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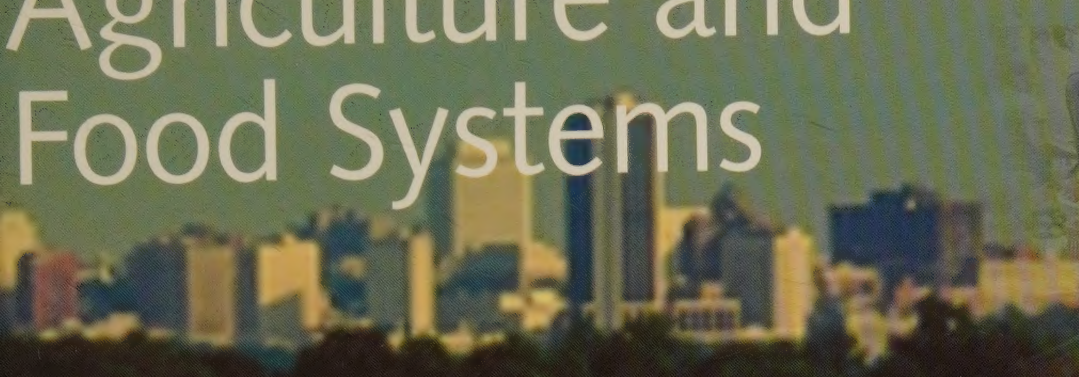

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Renewable Agriculture and Food Systems provides an international forum for original research and review articles on the biological, physical, social science, and policy aspects of alternative agriculture and food systems, focusing on the effective use of renewable resources and biodiversity in agro-ecosystems. The journal particularly welcomes multidisciplinary, holistic, systems research that addresses the multiple challenge of economically meeting basic human needs for food, fiber, and energy while maintaining essential natural and environmental resources.

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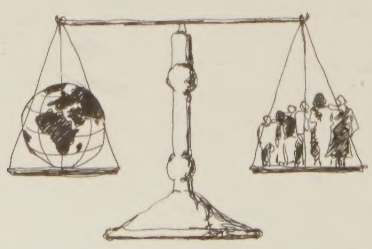

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Wallingford
Oxon OX10 8DE
UK
Tel: +44(0)1491 832111
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For Customers in North America:
CABI Publishing North America
875 Massachusetts Avenue
7th Floor
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MA 02139
USA
Tel: +1 617 395 4056
Fax: +1 617 354 6875
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A history of organic farming: Transitions from Sir Albert Howard's *War in the Soil* to USDA National Organic Program

J. Heckman*

Plant Biology and Pathology Department, Rutgers University, New Brunswick, NJ 08901, USA.
*Corresponding author: Heckman@aesop.rutgers.edu

Accepted 20 August 2005 **Review Article**

Abstract

The organic farming concept developed in the period prior to 1940 and was pioneered by Sir Albert Howard (1873–1947). Howard, born and educated in England, directed agricultural research centers in India (1905–1931) before permanently returning to England. His years of agricultural research experiences and observations gradually evolved into a philosophy and concept of organic farming that he espoused in several books. Howard's thinking on soil fertility and the need to effectively recycle waste materials, including sewage sludge, onto farmland was reinforced by F.H. King's book, *Farmers of Forty Centuries*. Howard developed a system of composting that became widely adopted. Howard's concept of soil fertility centered on building soil humus with an emphasis on how soil life was connected to the health of crops, livestock, and mankind. Howard argued that crop and animal health was a birthright and that the correct method of dealing with a pathogen was not to destroy the pathogen but to see what could be learned from it or to 'make use of it for tuning up agricultural practice'. The system of agriculture advocated by Howard was coined 'organic' by Walter Northbourne to refer to a system 'having a complex but necessary interrelationship of parts, similar to that in living things'. Lady Eve Balfour compared organic and non-organic farming and helped to popularize organic farming with the publication of *The Living Soil*. Jerome Rodale, a publisher and an early convert to organic farming, was instrumental in the diffusion and popularization of organic concepts in the US. Both Howard and Rodale saw organic and non-organic agriculture as a conflict between two different visions of what agriculture should become as they engaged in a war of words with the agricultural establishment. A productive dialogue failed to occur between the organic community and traditional agricultural scientists for several decades. Organic agriculture gained significant recognition and attention in 1980, marked by the USDA publication *Report and Recommendations on Organic Farming*. The passage of the Federal Organic Foods Production Act in 1990 began the era of accommodation for organic farming in the USA, followed by another milestone with official labeling as USDA Certified Organic in 2002. Organic agriculture will likely continue to evolve in response to ongoing social, environmental, and philosophical concerns of the organic movement.

Key words: Indore composting, humus theory of plant nutrition, the Law of Return, organic agriculture, USDA Certified Organic, F.H. King, E.B. Balfour, J.I. Rodale, Albrect Daniel Thaer, Justus von Liebig, Carl Sprengel

Introduction

Many people active in organic agriculture today are unaware of the important role played by Sir Albert Howard[1] and others of his generation, including F.H. King, Walter Northbourne, Lady Balfour, J.I. Rodale, and Louis Bromfield, in the development and diffusion of organic farming concepts. For a better understanding of organic concepts, there is still much that can be learned from reading the foundational writings of Sir Albert Howard. The recent rapid growth of the organic movement has resulted in a loss of connection with the historical figures and roots of organic agriculture. Scientists conducting organic farming research, farmers considering organic transition and the general public may benefit from knowing more of this history. It remains to be seen how much the situation has changed from the assessment more than two decades ago by Richard Harwood: 'There is an extremely dismal record of attempts in the USA to scientifically approach the study of organic agriculture'[2]. Also, the effective practice of organic farming requires more than a superficial knowledge of the USDA rules for organic certification[3].

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These and other assertions made in this paper are based on an analysis of the historical literature, over two decades of professional experience as an agronomist, and many years of collected observations as the son of an organic farmer, Norbert J. Heckman of Yorkshire, OH,[4] who began farming by the organic method around 1950. Here, I will briefly review the life and work of Howard and other historical figures involved in the development, evolution, and diffusion of organic agricultural concepts from the international stage to the USA, focusing on the most significant features and milestones of what is a long and complex history. A more comprehensive and related review is provided by Conford in *The Origins of the Organic Movement*[5]. Although biodynamics[4] is an important branch of organic farming that was founded by Rudolf Steiner, it is not a focus of this paper, which is primarily concerned with Howard's contributions. Furthermore, it has been noted elsewhere[5] that Howard 'was uncompromisingly skeptical about Steiner's biodynamic cultivation'.

Telling a history of organic farming—as with other great movements, such as alternative medicine—requires exploring the interplay between science, social values, economics, and the recalcitrance of established organizations to adopt new approaches. In tracing the historical trajectory from the genesis of Howard's major organic concepts and practices (a living connection between soil fertility and plant and animal health, the Law of Return and composting) to the widespread adoption of these beliefs and practices, one encounters a series of battles between intellectual and economic stakeholders. Although support for the organic movement has grown with public awareness, opposition to it has never gone away. These issues are reflected in the history of Howard's contributions to organic farming. The story of this development of organic concepts in the 1930s to their fate as expressed in the current USDA National Organic Program occurred in a series of stages—the development of organic concepts and methods, polarization around them, then their recognition, accommodation, and finally their further extension.

Organic Farming Concept Development

Although some concepts of organic farming predated his work, today Sir Albert Howard (1873–1947) is regarded by most as the founder and pioneer of the organic movement[5–7]. Born into an agricultural life, he never strayed far from it. Raised on a farm in England, and educated at Cambridge, he served for a time (1899–1902) as mycologist in the Imperial Department of Agriculture for the West Indies, before returning to England to teach agricultural science from 1903 to 1905 at South-Eastern Agricultural College at Wye[7]. He then moved to India where, for 26 years he directed several agricultural research centers before permanently returning to England in 1931. It was after his return that he became well known for his concepts and philosophy of organic farming. By drawing on his many years of agricultural research experience, he wrote several widely read books espousing his concepts and theories of composting, soil fertility, and health and disease.

In 1943, Howard published the book *An Agricultural Testament*, in which he described a concept that was to become central to organic farming—the importance of utilizing available waste materials to build and maintain soil fertility and humus content[8]. According to what he called 'The Law of Return', he strongly advocated the recycling of all organic waste materials, including sewage sludge, back to farmland. Recalling his experiences in India, he described his original 'Indore' (after a region in India) method of composting. Here, he prescribed a certain pile size, heat, moisture, aeration, and mix of plant, animal, urine-soaked earth, and ash materials as a proper composting recipe[8,9]. Especially important to a good mix of composting materials, Howard stressed, were residues from both plants and animals. He was not alone in his thinking and found support for his ideas on soil fertility and the need for effective recycling of waste materials to farmland in F.H. King's book[10], *Farmers of Forty Centuries, Permanent Agriculture in China, Korea, and Japan*, which appeared in 1911 but then lay in relative obscurity. Such a sustainable soil fertility management was vividly described by Victor Hugo[11]: 'Not a Chinese peasant goes to town without bringing back with him, at the two extremities of his bamboo pole, two full buckets of what we designate as filth. Thanks to human dung, the earth in China is still as young ...'

In *Farming and Gardening for Health or Disease* (later published as *Soil and Health*), Howard introduced the idea that disease, whether in plants, animals, or humans, was caused by unhealthy soil and that organic farming techniques would make the soil and those living on it, healthy[12]. As evidence he cited his observation that animals fed with crops grown in humus-rich soil were able to rub noses with diseased animals without becoming infected. More generally, he argued that crop and animal health was a birthright and that the correct method for dealing with a pathogen was not to destroy the pathogen but rather to try to learn from it or to 'make use of it for tuning up agricultural practice'[12].

Howard's concept of soil fertility was centered on building soil humus with an emphasis on a 'living bridge' between soil life, such as mycorrhizae and bacteria, and how this chain of life from the soil supported the health of crops, livestock, and mankind[12]. While Howard acknowledged that soluble salts from humus were important to plant nutrition, he also wrote that plants 'do compensate themselves by absorbing organic nitrogen'[12]. Here, Howard disagreed with both Albrect Daniel Thaer (1752–1828) who advocated the Humus Theory of Plant Nutrition and with Justus von Liebig (1803–1873) who advocated that plants 'find new nutritive material only in inorganic substances'[13].

Like many of his generation, Howard was probably not aware of the work of Carl Sprengel (1787–1859), when he described Liebig's work as 'a great advance' and

'illuminating' and that 'artificial fertilizers were born out of the abuse of Liebig' discoveries'[12]. Sprengel, Thaer's student, refuted the humus theory and played an important role in the development of the theory on mineral nutrition of plants, and the formulation of the Law of the Minimum[13]. Liebig never acknowledged Sprengel's discoveries and passed them off as his own[13] (Liebig is often given sole credit for these discoveries still today in soil science textbooks[14]). Since he was indefatigable in his struggle for the acceptance of the doctrine of mineral nutrition of plants, Liebig used his reputation as a world-renowned and celebrated scientist to devalue the important role of humus in soil fertility and soil quality[13]. While Howard recognized the significance of Liebig's writings on agricultural chemistry, he was no Leibig devotee. Howard thought that Liebig was 'a sinner' for vigorously combating the so-called humus theory and instituting the so-called 'NPK mentality'[12]. One of Howard's main criticisms was that Liebig focused attention on soil chemistry to the neglect of soil biology and physics[12]. As a result of this single minded focus on chemistry, the once great appreciation for soil organic matter fell to a position of low esteem. In recent decades, however, there has been a renewed appreciation for soil organic matter[15]. Howard never lost his appreciation for humus and continued to extol its profound influence on the health of soils, plants, animals, and mankind.

While the Sprengel–Liebig Law of the Minimum became a widely accepted agronomic principle[13,14], an appreciation for Howard's Law of Return was limited mostly to organic farmers. Consequently, in non-organic farming versus organic farming, the value placed on the return of organic waste materials to the land has typically been viewed differently. With ready access to concentrated chemical fertilizers in non-organic farming, disposal became the primary interest in land application of organic waste materials. In organic farming, a high value continues to be placed on organic waste materials for building and maintaining soil organic matter content as well as nutrient recycling.

Although Howard knew that certain nutrients could be severely limiting in some soils, he opposed using chemical fertilizers[5,16] even though they could more easily correct specific nutrient limitations than could the use of compost. Thus, Howard's extreme position against any use of chemical fertilizers created a challenging situation for organic farmers attempting to balance nutrient supply, i.e., to effectively deal with the Law of the Minimum. Howard's hard-line position against the use of chemical fertilizers, however, was not shared by some of his contemporary supporters who felt that the use of artificial fertilizers could sometimes be justified[4]. Howard was, however, open to the use of some naturally occurring mineral sources such as pulverized rocks[8,17].

Liebig's absolute concept of 'only' inorganic nutrient uptake by plants is obviously inaccurate[18] and yet it has persisted in modern soils literature[19]. This represents a case of mechanistic rigidity in the history of science that illustrates a lack of a functional understanding of natural systems[20]. Likewise, the hard-line position of Howard against the use of any chemical fertilizers may represent a case of extremism. Moreover, Howard's extreme position contributed to the common but mistaken impression that organic is simply defined as farming without the use of synthetic fertilizers.

In Howard's long and distinguished career as a scientist, he made discoveries and contributions relating to a wide range of areas beyond composting and soil fertility. These areas included plant breeding, irrigation, mycorrhizae, root systems, soil aeration, fruit tree cultivation, post-harvest produce transport, weed management, and diseases of plants and humans[12,21]. For these sound contributions to agriculture, he was knighted in England. While having earned the respect of his scientific peers, in his later years Howard became extremely critical of the agricultural establishment[16,21,22]. His ideas on humus, soil fertility, and disease became viewed as exaggerations of otherwise fundamentally sound ideas and he was becoming known as an extremist[21]. In 1946, he acted out his new role of agricultural activist most explosively in *The War in the Soil*[16]. He opened this book with the powerful assessment that: 'The war in the soil is the result of a conflict between the birthright of humanity—fresh food from fertile soil—and the profits of a section of Big Business in the shape of the manufacturers of artificial fertilizers and their satellite companies who produce poison sprays to protect crops from pests and who prepare the various remedies for the diseases of live stock and mankind.' Howard loudly criticized field plot and statistical methodology used in classical research at the Rothamsted agricultural experiment station that was established to compare the long-term effects of artificial fertilizers (inorganic chemical fertilizers) and manure. He thought that these studies were flawed because they did not exclude invasion from burrowing earthworms into the chemically fertilized plots, relied on continuous cultivation without crop rotation, and used new seeds from an outside source.

A true comparison of organic farming to non-organic farming, Howard argued, would not be an easy task[16]. For example, he suggested that such a comparison should begin with 'two large areas of similar worn-out land side by side', a period of at least ten years, and that a minimum of five years was required for the conversion to an organic system[16]. He further suggested that such a study should compare responses of soils, earthworms, crops, and livestock. Clearly, Howard favored the study of whole systems over reductionism. Such a study comparing organic and non-organic farms was attempted from 1939 to 1969 in England by Lady Eve Balfour. Her observations from this comparison of whole farms were described in her widely read book *The Living Soil and the Haughley Experiment* first published in 1943 and republished in 1974[23].

Although Howard was a passionate advocate of organic farming, he did not coin the term 'organic' in reference to

this system of agriculture. But in 1940, in *An Agricultural Testament*, Howard describes the main characteristics of what he called 'Nature's farming'. 'Mother earth never attempts to farm without live stock; she always raises mixed crops; great pains are taken to preserve the soil and prevent erosion; the mixed vegetable and animal wastes are converted into humus; there is no waste; the processes of growth and the processes of decay balance one another; ample provision is made to maintain large reserves of fertility; the greatest care is taken to store the rainfall; both plants and animals are left to protect themselves from disease'[8].

Walter Northbourne was apparently the first to apply the word 'organic' in application to farming[24]. In 1940, Northbourne published an influential book, *Look to the Land*, in which he elaborated on the idea of the farm as an 'organic whole'—in the philosophical sense, 'organic' refers to 'having a complex but necessary interrelationship of parts, similar to that in living things'. This concept of organic is similar in many respects to the holistic ideas more recently expressed by James Lovelock in the 'Gaia Hypothesis' and Lynn Margulis in her book *Symbiotic Planet* but on the smaller scale of a whole farm as a symbiotic unit[25]. In this respect, the organic farmer functions in concert with the symbiotic unit by being in daily contact with and having a feeling for the whole farm organism. It is also important to distinguish this meaning of 'organic' as it applies to a system of farming from the common misunderstanding that 'organic' specifically refers to the carbon-based chemistry of the fertilizers that are often used in organic farming.

Polarization into Organic versus Non-organic

While Howard played a pivotal role in developing the concepts of organic farming and popularizing them around the world, he was also a polarizing figure. The period from about 1940 to 1978 may be called the era of polarization of agriculture into organic and non-organic camps. During this period, there was little effective dialogue between the organic community and conventional agriculture. American businessman and publisher, Jerome Rodale, was an early convert to organic farming as a result of reading the works of Howard[26,27]. So moved was Rodale by Howard's organic vision—which he described as being hit by a 'ton of bricks'—that he purchased a farm near Allentown, PA, and began experimenting with composting and organic farming techniques. In 1942, Rodale began publishing *Organic Farming and Gardening* magazine with Howard serving as the associate editor[26]. Through this magazine and other publications, Rodale diffused and popularized organic concepts in the US[27]. Rodale's 1945 book *Pay Dirt*[17], with an introduction by Howard, summarized organic farming concepts for a wide audience. His missionary zeal for promoting organic farming in the USA is suggested by the title of his 1948 book[28], *The Organic Front*, which followed on the heels of Howard's book, *The War in the Soil*. Both Howard and Rodale saw the conflict of organic versus non-organic agriculture as a struggle between two different visions of what agriculture should become as they engaged in a war of words with the agricultural establishment[16,28].

Although Howard was not a fan[5] of biodynamic farming[6], Rodale was interested in the work of Ehrenfried Pfeifer, a protégé of Rudolf Steiner. Rodale often visited Pfeifer's farm in Pennsylvania to share ideas and he published articles by Pfeifer in *Organic Farming and Gardening* magazine[29].

Initially, agriculturalists from the non-organic establishment largely ignored the organic farming movement. Agricultural colleges and experiment stations, however, were increasingly besieged with letters of inquiry from the public[30] and it became impossible to ignore the organic movement. One of the first attempts to respond to the organic advocates was undertaken by Firman E. Bear, a prominent soil chemist at Rutgers University, who in a 1947 article 'Facts ... and Fancies About Fertilizer'[30], referred to Sir Albert Howard, E.B. Balfour, J.I. Rodale, and E.H. Faulkner as 'gloomy prophet[s]'. Similarly, in 1963, Emil Truog, a soil scientist at the University of Wisconsin, called the 'Organic School' a 'Cult'[31]. Other articles critical of the organic movement were published during this period of polarization such as 'Organics only?—Bunkum!'[32], and 'The great organic gardening myth'[33].

These critics argued that there is no difference between nitrogen derived from organic materials and inorganic fertilizer nitrogen because organic sources needed to be mineralized to ammonium or nitrate (i.e., inorganic N) before they are available to plants. This notion that plants only uptake inorganic forms of nutrients may be traced back to the writings of Liebig and persists to this day in literature that is critical of organic farming[19]. Current literature, however, provides evidence that some plants can uptake and utilize limited amounts of organic forms of nitrogen such as amino acids and peptides[18]. Not only were those early arguments incorrect, but they also misrepresented the principles of organic farming as if it were defined by carbon (organic) chemistry rather than a philosophy of living systems. Another implied argument is that the biological processes occurring in the soil and responsible for mineralization are of no value to soil quality. Recently, however, there has been an increasing appreciation for the biological processes associated with the soil food web[15]. This may be seen as a rebirth of Howard's thinking regarding important biological linkages between soil organisms that extend to and influence the health of crops, livestock, and humans.

Notable American advocates of building soil fertility by using organic farming methods included Louis Bromfield and Edward Faulkner, both of whom were popular agricultural writers but not organic purists[5,16,34,35].

In addition to novels that were made into movies by Hollywood, Louis Bromfield published the widely read books *Pleasant Valley* (1945), *Malabar Farm* (1948), and *Out of the Earth* (1950)[35–37]. Edward Faulkner, author of the best selling book *Plowmans Folly* (1943), was a controversial figure in his time but is now regarded as a pioneer of no-till and conservation tillage farming[34,38].

The era of polarization also occurred at a time when problems in soil fertility and in crop pest control were being treated by the so-called 'miracles' of chemistry. Technical optimism[39,40] was not, however, limited to agriculture but also prevailed in all facets of life during the era lauded by *Time* magazine in 1961 as the 'Age of Science'. Atomic power, for example, was being sold to the public with unbounded optimism as a safe and almost unlimited power source that would be too cheap to meter[40]. In agriculture, the publication of *Silent Spring* by Rachel Carson in 1962 began a change of focus and attention as it ignited the environmental movement while raising concerns about the excessive use of pesticides in agriculture[41,42].

Over the next two decades, public interest in the organic method continued to grow. For example, the circulation of *Organic Gardening* magazine increased from 260,000 in 1960 to 1,300,000 in 1980[27]. Many factors, such as the migration of some people from the cities to the country, the growing environmental movement, and the anti-establishment social revolution, were responsible for the increasing popularity of Rodale Press publications. A review article[27] about the Rodale Press and *Organic Gardening* stated that 'Over time, the polarization between land-grant colleges and Rodale Press decreased to the extent that a few organic gardening courses began to appear about 1970, serving mostly students who were not in the applied agricultural departments.' The agricultural community, however, being very proud of its recent success in markedly increasing productivity using agricultural chemicals, continued to reject organic farming as a viable alternative[43].

Recognition for Organic Agriculture

The period from 1979 to 1990 may be described as the era of recognition for organic farming at a national level in the USA. With a growing public interest in organic food and farming, interest in establishing standards for organically produced foods also increased[44]. As a sign of the new times, in 1979, California passed a law establishing a legal standard for organic production.

Under the direction of Secretary of Agriculture, Robert Bergland, the USDA began surveying the organic farming sector. In 1980, the USDA published the *Report and Recommendations on Organic Farming* for the expressed purpose of 'increasing communication between organic farmers and the USDA'[45]. In 1981, the American Society of Agronomy held a Symposium on Organic Farming to examine the question 'Can organic farming contribute to a more sustainable agriculture ...?' They concluded: 'The most probable answer is that it most definitely can ...' and also that '... the soils for the two farming systems may be quite different, each with its own unique chemical and biological properties and crop production capabilities'[46]. Although the USDA publication[45] did not cite Howard's work on organic farming, the American Society of Agronomy symposium publication[46], *Organic Farming: Current Technology and its Role in a Sustainable Agriculture*, did.

This new attention and recognition led to a backlash in 1981 from the incoming Reagan administration, which tried to bury the USDA *Report and Recommendations on Organic Farming*[47]. The new administration also abolished the recently established position of Organic Resources Coordinator, held by Garth Youngberg who had been a member of the USDA Study Team for Organic Farming. During this time, a former Secretary of Agriculture, Earl Butz, released his infamous statement that millions would starve if all farmers adopted organic methods[43]. Clearly the USDA and the US political structure were not ready to promote widespread adoption of organic farming.

In spite of the changing political situation at the national level, the already published USDA *Report and Recommendations on Organic Farming* continued to be read, and served to stimulate a growing interest in organic farming. A few land-grant colleges began to offer courses in organic farming to serve the interests of applied agricultural students[27]. In the early 1980s when organic farming was deemed a subject area worthy of classroom time and attention, this author (at that time as a graduate student at the University of Maryland) recalls feeling that this represented a significant level of recognition for what was previously considered unacceptable in academic agriculture.

It was also around this same time that some advocates for organic farming began supporting the term 'sustainable agriculture' in hopes that it would invite respect for organic farming[47,48]. One of those advocates, Garth Youngberg, later established an effective professional organization to support sustainable agriculture, now known as the Henry A. Wallace Institute for Alternative Agriculture. Under the broader umbrella of sustainable agriculture, this institute has been an important supporter of organic farming. While organic farming and sustainable agriculture are both part of the alternative agriculture movement, these terms are not synonymous[49].

While the conflict[16] that Howard described as a 'War in the Soil' did not end in the 1980s, organic farming was clearly gaining a new level of legitimacy and recognition. In the 1980s, while there were summit meetings between the two Cold War powers, there was also a kind of 'Summit Meeting' held between the Rodale Press (representing organic farming) and the Fertilizer Institute and the Potash and Phosphate Institute (representing the chemical fertilizer industry)[50]. Also in the 1980s, some USDA

scientists carried out research in association with the Rodale Institute[51].

Accommodation for Organic Agriculture

The passage of the Federal Organic Foods Production Act of 1990 marks an era of accommodation for organic farming in the USA[52]. This Act set out to:

1. establish national standards governing the marketing of organically produced products,
2. assure consumers that organically produced products meet a consistent standard, and
3. facilitate inter-state commerce in both fresh and processed organic foods.

The writing of the official USDA rules for what defined organic farming and organic food required more than a decade. Initially, the proposed standards did not prohibit the use of sewage sludge, food irradiation, and genetically modified organisms (GMOs). But these initial allowances resulted in an enormous public outcry, which eventually led to their elimination from the final rules, which were officially unveiled with labeling as USDA Certified Organic on October 21, 2002.

Although it is impossible to know today what Howard would think of the USDA rules, it is interesting to note that he encouraged the use of sewage sludge because the recycling of human manure was consistent with the Law of Return. Nevertheless, given Howard's concern over poison sprays, it seems unlikely that he would approve of the contaminating substances that are now known to be present in some sewage sludges[53]. Although GMOs were not an issue in Howard's time, his stated position against artificial insemination would seem to suggest opposition to other such 'artificial' technologies[12]. The USDA rules, which allow for the use of some synthetic micronutrient fertilizers, when a need is demonstrated, would seem to collide with Howard's opposition to the use of any chemical fertilizer[16].

As far back as 1942, J.I. Rodale presciently predicted: 'One of these fine days the public is going to wake up and will pay for eggs, meat, vegetables, etc., according to how they were produced'[26]. In the early years of the organic movement and before there was a significant market for organic products, organic farming was done out of a passion for the philosophy[3]. Today, with the growing demand for organic products, price premiums are, in some cases, attracting new converts to organic farming for financial survival. While organic farming and organic food continue to be the target of criticism by skeptics in agriculture and food science, USDA Certified Organic appears to be here to stay. During the past 15 years, the market demand for organically produced food has increased by about 20% annually[54–56]. Nationally, organic product sales currently exceed $8 billion and there is an estimated 2.3 million acres farmed organically[54–56]. With new incentives from the USDA to transition land into certified organic production, these growth trends are actively encouraged[56].

Beyond USDA Certified Organic

The establishment of USDA standards for organic production was an important milestone in the organic movement. It also served to formally define organic as 'A production system that is managed in accordance with the Organic Foods Production Act and regulations to respond to site-specific conditions by integrating cultural, biological and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity'[55]. This definition, however, has not satisfied all within the organic movement[57,58]. Some would like to see a greater emphasis placed on issues such as locally produced foods, biological diversity, raising livestock humanely and on pastures, certified raw dairy foods, renewable energy, environmental stewardship, subtle energies, and social justice[58–65].

Sir Albert Howard would likely be dissatisfied with the current status of the organic movement. In 1946, he declared[16] that 'The downfall of the artificial manure industry and of its satellite companies will mark the end of the war in the soil' and that 'The last episode in the war in the soil is the conversion of the agricultural experiment stations and the agricultural colleges all over the English-speaking world from inorganic to organic farming'. While the agricultural chemical industry exhibits no sure sign of a downfall, there has been some progress in the conversion of agricultural experiment stations and colleges to organic farming. Some land grant universities as well as other agricultural institutions are now offering courses in organic production and are establishing certified organic experiment station land[54]. Iowa State University, has already employed America's first organic agriculture extension specialist[66]. Similar positions are being created at other institutions. It is impossible to predict the outcome of this current trend. It is, however, quite possible that non-organic agriculture will benefit from the research and extension programs on soil fertility and pest management conducted under the organic model. For example, studies have shown that, in some cases, organic management of soils may reduce pest preference for the crop[67]. Research toward a better understanding of such biological processes involved would benefit agriculture in general.

Ignoring Howard's 'Law of Return' has resulted in the accumulation and poor utilization of manures and other organic wastes in some regions of the US. Meanwhile, a tendency to practice the Law of Return excessively by some organic and non-organic farmers has caused nutrients, such as P, to accumulate in soil to levels of environmental concern[68]. Transitions to organic farming on soils that today often have a higher nutrient status due to previous chemical fertilizer inputs may benefit subsequent organic production but careful attention to the Law of Return will be required to maintain soil fertility. The current ban on the use of human manure in organic farming makes complete nutrient cycling—as originally recommended by Howard—difficult if not impossible for wide-scale sustainable organic

farming. Composting and recycling systems, as described in *The Humanure Handbook, A Guide to Composting Human Manure* by Joseph Jenkins[69], could help solve the human manure problem provided the emotional, technical, and policy concerns can be overcome. Although careful attention to Howard's Law of Return can never reach 100% efficiency in nutrient cycling, there is a huge potential for improving the recycling of plant and animal wastes to restore and maintain soil fertility in the US and the world[70]. To the extent to which research, extension, and agricultural policy encourage the effective utilization of waste materials with their associated nutrients for soil fertility maintenance, as originally envisioned by Howard, the need for chemical fertilizers could be reduced accordingly.

Howard contributed significantly to developing the art and science of composting[9] that continues in today's organic farming but with new standards for compost pile temperature maintenance and turning. While the USDA standards for composting are important for ensuring protection from pathogens that can come from manure, the greater requirement for equipment and capitalization has unfortunately discouraged the composting of manure by some smaller organic farmers.

While much of Howard's passion and vision for an organic agriculture has not come to fruition in the National Organic Program nor in the current status of organic farming in the USA, Howard and other organic advocates did inspire generations of farmers, gardeners, and consumers to change their philosophical views on waste materials, soil management, soil quality, health and disease, pesticides, synthetic materials, and the environment[39,43,71]. Tension and debate continues between the different philosophical, political and scientific ideas and ideals of organic and non-organic farming and even within the organic farming community itself. As these differences play out, they can be a positive and creative force to stimulate new lines of agricultural research leading to more environmentally sound and sustainable agriculture, provided there is open communication and the prevailing agricultural paradigms are allowed to be questioned.

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Banded herbicide, rotary hoeing and cultivation effects on weed populations in ridge-tilled soybean

Thomas W. Jurik*

Department of Ecology, Evolution, and Organismal Biology, Iowa State University, Ames, IA 50011 USA.
*Corresponding author: jurik@iastate.edu

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Abstract

Can banded herbicide be eliminated in ridge-tilled soybean (*Glycine max*)? The effects of banded herbicide, rotary hoeing and cultivation on weed populations and soybean yield in a ridge-tillage system were tested on three farms in Iowa, USA in 1989 and 1990. In 1989, plots either had no herbicide or had herbicide banded in the row at planting in mid-May; all plots received two rotary hoeings and two cultivations. In 1990, treatments were banded herbicide with no rotary hoeing, banded herbicide with one rotary hoeing, and no herbicide with one or two rotary hoeings; all plots received two or three cultivations. In both years, over all weed species [primarily giant foxtail (*Setaria faberi*), Pennsylvania smartweed (*Polygonum pensylvanicum*) and redroot pigweed (*Amaranthus retroflexus*)], seedling emergence was highest in late May and early June, with few seedlings emerging after mid-June. Weed populations were highest in May and June, after which rotary hoeing and cultivation reduced weed numbers in all plots. There were no consistent differences among treatments in weed numbers in early August for the 2 years. In both years, there was no significant difference in soybean yield among treatments. Within-farm mean yields ranged from 2.26 to 3.01 Mg ha^{-1} among farms in 1989 and from 2.07 to 2.93 Mg ha^{-1} among farms in 1990. Ridge-tillage without herbicide was generally equivalent to ridge-tillage with banded herbicide, with respect to total number of weeds and number of broad-leaved weeds remaining in August after tillage, and to soybean yield.

Key words: conservation tillage, mechanical weed control, seedling emergence, weed density, weed population dynamics

Introduction

Ridge-tillage has been used to a limited extent since the 1950s in the midwestern USA[1]. It may provide an alternative to extensive use of herbicide to control weeds. However, wider adoption of ridge-tillage has been slowed by a variety of concerns, including tillage costs, long-term effects on weed populations, and lack of knowledge of the best combinations of techniques to use in the system. Despite the fuel, labor and machinery costs associated with its tillage operations, ridge-tillage appears to be an economically viable system, with returns competitive with those of other tillage systems[2].

The effectiveness of ridge-tillage relative to other tillage systems in controlling weeds has been examined in several studies[3–5]. There has been concern that reduced-tillage systems will require more herbicide to control weeds. This may occur in no-till systems[6]. However, the mechanical operations of ridge-tillage can greatly reduce the number of weeds present, such that a ridge-tillage system with herbicide banded in the row may control weeds as well as ridge-tillage with broadcast herbicide[7]. Can herbicide applications be further reduced in a ridge-tillage system? Rotary hoeing is often used to control weeds in ridge-tillage systems, after planting has produced a relatively flat surface topography; cultivations to rebuild the ridges further control weeds. However, little information is available on how well weeds are controlled by rotary-hoeing and cultivation in a ridge-tillage system and whether herbicide can be eliminated. The combination of rotary hoeing and cultivation provided good weed control in moldboard-plowed soybeans[8] and chisel-plowed corn[9], even when reduced herbicide rates were used.

The objective of this study was to contrast ridge-tillage with and without herbicide banded in the row at planting, to evaluate whether rotary hoeing and cultivation are an effective substitute for banded herbicide with respect to weed control and soybean (*Glycine max*) yield.

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Table 1. Soybean cultivars and herbicides used, cultural conditions, plant densities and rainfall in 1989 on three farms in Iowa.

	Farm		
	Graaf	**Grau**	**Hartsock**
Cultivar	Pioneer 1981	Hill 2275	Soi 226
Herbicide	Chloramben	Metolachlor + metribuzin	Metolachlor
Herbicide rate (kg ha^{-1})[1]	0.79[2]	0.57[3] + 0.08[3]	0.91[3]
Herbicide band width (cm)	15	30	25
Mean row width (cm)	76	100	91
Row length (m)	800	400	400
Rows/plot	6	8	8
Seeding rate (number ha^{-1})	507,000	378,000	395,000
July soybean plant density (number ha^{-1})			
with banded herbicide[4]	264,000	284,000	329,000
without herbicide[4]	262,000	287,000	297,000
Rainfall (cm)			
May	4.8[5] (9.3)[6]	3.6 (9.3)[6]	1.8 (9.3)[6]
June	6.1[5] (11.2)[6]	7.6 (11.2)[6]	4.3 (11.2)[6]
July	7.5[5] (9.7)[6]	7.7 (9.7)[6]	3.8 (9.7)[6]
August	4.6[5] (10.4)[6]	4.8 (10.4)[6]	7.2 (10.4)[6]

[1] Rate per unit herbicide band area.
[2] kg a.e. ha^{-1}.
[3] kg a.i. ha^{-1}.
[4] Treatments also received rotary hoeing and cultivation.
[5] Values from Pocahontas, Iowa (US National Climatic Data Center).
[6] Long-term normal value for Pocahontas, Iowa (US National Climatic Data Center).

Materials and Methods

Field sites

Four privately owned and operated farms were used for field studies in 1989 and 1990. The Graaf farm was near Palmer and Pocahontas, the Grau farm near Newell, the Hartsock farm near Rolfe, and the Thompson farm near Boone, Iowa, USA. Farmers used their own equipment, seed and herbicide to establish, grow and harvest soybean on the field sites. Corn–soybean (Graaf, Grau and Hartsock farms) or corn–soybean–corn–oats–hay (Thompson farm) rotations had been used on the sites. Different fields on each farm were used in 1989 and 1990. A severe rain storm on 23 May 1989 potentially damaged the treatments on the Thompson farm, so the experiment was terminated on that site for that year. Similarly, a severe wind/hail storm on 19 June 1990 destroyed the Graaf farm experiment. Thus, data are available for only three farms in each year. In 1989, plots on the Graaf, Grau and Hartsock farms were primarily on Clarion (fine-loamy, mixed, mesic Typic Hapludolls) and Webster (fine-loamy, mixed, mesic Typic Haplaquolls) soils[10,11]. The Hartsock field also included some Nicollet soil (fine-loamy, mixed, mesic Aquic Hapludolls), and the Grau farm also included some Nicollet and Canisteo [fine-loamy, mixed (calcareous), mesic Typic Haplaquolls] soils. In 1990, the Thompson farm plots were on Clarion and Webster soils[12], while the Hartsock and Grau farm plots were on Canisteo soil.

Experimental treatments

Soybean cultivars, herbicides used, cultural conditions, plant densities and May–August rainfall for the study farms are shown in Table 1 for 1989 and in Table 2 for 1990. Although the soybean cultivars and most of the herbicides used in this study generally have been replaced by others in the years since 1990, a key point noted below in the Results and Discussion is that all the herbicide treatments in the ridge-till system provided good to excellent weed control and thus provided a standard of reference similar to what might be expected when using current formulations of herbicides and crop varieties in a ridge-till system. Rainfall was recorded by each farmer. Rainfall values were compared with long-term mean values from Pocahontas, Iowa (located between the Graaf, Grau and Hartsock farms) and Boone, Iowa (near the Thompson farm), as reported by the US National Climatic Data Center. Seeding rates are values reported by the farmers. Dates of planting, rotary hoeing and cultivation are given in Table 3. Herbicide was banded in the row at planting, in those treatments receiving herbicide. On each site, there were six replications of each treatment, arranged in a randomized complete block design, with each set of two (in 1989) or three (in 1990) treatment plots constituting a block. Each replicate plot consisted of six or eight rows, 400 m or 800 m in length (Tables 1, 2). All rows were oriented N–S except on the Graaf farm, where they ran E–W. Soybean plant densities in July 1989 and early August 1990 were estimated from counts in three 5-meter lengths of row in each plot.

Table 2. Soybean cultivars and herbicides used, cultural conditions, plant densities and rainfall in 1990 on three farms in Iowa.

	Farm		
	Grau	**Hartsock**	**Thompson**
Cultivar	Latham 750	Latham 671	Mohawk
Herbicide	Metolachlor + metribuzin	Metolachlor	Chloramben
Herbicide rate (kg ha^{-1})[1]	0.57[2] + 0.08[2]	0.76[2]	0.79[3]
Herbicide band width (cm)	30	20	20
Mean row width (cm)	91	91	91
Row length (m)	800	800	400
Rows/plot	8	8	8
Seeding rate (number ha^{-1})	395,000	430,000	445,000
August soybean plant density (number ha^{-1})			
banded herbicide, 0 rotary hoeing[4]	259,000	299,000	221,000
banded herbicide, 1 rotary hoeing[4]	219,000	319,000	203,000
no herbicide, 1 or 2 rotary hoeings[4]	212,000	264,000	206,000
Rainfall (cm)			
May	11.3 (9.3)[5]	11.2 (9.3)[5]	21.1 (11.1)[6]
June	35.2 (11.2)[5]	18.8 (11.2)[5]	23.1 (13.0)[6]
July	7.8 (9.7)[5]	11.9 (9.7)[5]	12.2 (8.8)[6]
August	16.0 (10.4)[5]	8.6 (10.4)[5]	6.7 (9.9)[6]

[1] Rate per unit herbicide band area.
[2] kg a.i. ha^{-1}
[3] kg a.e. ha^{-1}
[4] Treatments also received cultivation.
[5] Long-term normal value for Pocahontas, Iowa (US National Climatic Data Center)
[6] Long-term normal value for Boone, Iowa (US National Climatic Data Center).

In 1989, the experimental treatments were either herbicide banded over the row at planting or no herbicide was used. All plots received two rotary hoeings, in late May and early June, and two ridge-building cultivations, in June and early July (Table 3). In 1990, three experimental treatments were used. Treatments were herbicide banded over the row, with no rotary hoeing but two cultivations; herbicide banded over the row, with one rotary hoeing and two cultivations; and no herbicide, with two rotary hoeings and two cultivations. However, wet spring weather caused the number of rotary hoeings and cultivations to vary among farms in the no herbicide treatment. On the Grau and Hartsock farms, one rotary hoeing and three cultivations were used instead of the planned sequence of two rotary hoeings and two cultivations (see Table 3).

Table 3. Dates of planting, rotary hoeing and cultivation in 1989 and 1990 on four farms in Iowa.

	Farm			
	Graaf	**Grau**	**Hartsock**	**Thompson**
1989				
Planting	12 May	13 May	17 May	–
Rotary hoeing				
First	19 May	16 May	19 May	–
Second	24 May	31 May	28 May	–
Cultivation				
First	10 June	9 June	14 June	–
Second	22 June	5 July	1 July	–
1990				
Planting	–	30 May	5 June	1 June
Rotary hoeing				
First	–	25 June	25 June	4 June
Second	–	–	–	25 June
Cultivation				
First	–	6 July	5 July	27 June
Second	–	15 July	22 July	17 July
Third	–	1 August	30 July	–

Weed populations

Weed populations were sampled from late April to early August, after which there was essentially no further seedling emergence and no tillage operations. From planting through July, sampling was timed as much as possible to occur the day before tillage operations. Each plot was sampled a total of nine times in 1989 and 12 times in 1990. Sample locations within a plot varied among dates, to avoid a repeated-measures design. A rectangular sample area was defined as the distance between two rows of soybean plants × a distance along a row. Distance along a row, and hence size of the area sampled in each plot, varied over the growing season, but was uniform within a farm during any one sampling date. Total area sampled in each plot typically was 4–12 m^2 in May and June when seedling densities were high, but in late July and August was as large as 600 m^2 in each plot (nearly 1/10 the total plot area) when weed densities were much lower. The increase in

Table 4. Common weed species present at four farms in Iowa in 1989 (x) and 1990 (y). Foxtail species, Pennsylvania smartweed and redroot pigweed together typically constituted >90% of the weeds present on a site. Other species in the table were often present but had low abundances. Nine other species (not shown) were recorded only sporadically. The Thompson and Graaf farms were not studied in 1989 and 1990, respectively.

	Farm			
Taxon	**Graaf**	**Grau**	**Hartsock**	**Thompson**
Common cocklebur (*Xanthium strumarium* L.)	x	y	x	y
Common lambsquarters (*Chenopodium album* L.)	x	x	xy	y
Foxtail species (*Setaria* spp.)	x	xy	xy	y
Kochia (*Kochia scoparia* (L.) Schrad.)		xy	xy	
Pennsylvania smartweed (*Polygonum pensylvanicum* L.)	x	xy	xy	y
Redroot pigweed (*Amaranthus retroflexus* L.)	x	xy	xy	y
Smooth groundcherry (*Physalis subglabrata* Mack. and Bush.)	x	xy	xy	y

sample area decreased the variability among samples that would otherwise have occurred if smaller sample areas had been used with the low weed densities in late July and August.

On each sampling date, number of seedlings (plants < 2 cm tall) and plants >2 cm tall of all weed species were recorded in each sample area. The 'seedlings' category thus included plants that were presumed to have emerged since the previous sample date, and graphs of seedlings present (see Results) can be interpreted as approximate rates of seedling emergence. Patterns of emergence based on this procedure were similar to patterns derived in 1990 from small (0.25 m^2) subplots on the sites in which seedlings were counted and removed on each sample date (data not shown). The category of 'plants >2 cm' includes plants of various ages and sizes that may have survived previous tillage operations.

Statistical analyses

Within a year, values for weed populations on 1 August or for soybean yield (13% moisture) were compared over all farms using analysis of variance (ANOVA)[13] for a nested design, with main effects of farms, blocks (nested within farms) and herbicide/rotary hoeing treatment and a farm × herbicide/rotary hoeing treatment interaction term (alpha = 0.05).

Results and Discussion

Rainfall in 1989 (Table 1) was lower than normal on all farms but was distributed fairly evenly over the growing season on all farms, so that soybeans exhibited no apparent symptoms of moisture stress. In 1990, rainfall was above normal in May and early June but was near normal after mid-June (Table 2). In general, the same weed species were found on a given farm in both years (Table 4), although there was some variation because different fields were used each year. Foxtail species (*Setaria* spp.), Pennsylvania smartweed (*Polygonum pensylvanicum* L.) and redroot pigweed (*Amaranthus retroflexus* L.) were found on all four farms and typically totalled >90% of the weeds on a site; values for those taxa are presented here. Other species were much less common, but are included in the totals over all species. Foxtail species included primarily giant foxtail (*Setaria faberi* Herrm.), with lesser amounts of green foxtail [*Setaria viridis* (L.) Beauv.] and yellow foxtail [*Setaria glauca* (L.) Beauv.]; values for these taxa are here combined and called 'foxtail species'. Giant foxtail was the most common foxtail species found as adult plants. No other genus of grass was commonly found. Thus, the total number of broad-leaved individuals presented below is essentially the total number of individuals of all species minus the number of individuals of foxtail species. Conservation tillage systems[14] such as ridge-tillage may differ in the weed species present[15], because of differences in selection regimes and growth conditions, but there are no unique problems presented by ridge-tillage in this respect, and the weed species recorded here are commonly found throughout the state.

Patterns of weed population numbers were similar in 1989 and 1990 on all farms, except that in 1990 seedling emergence in late spring was slightly later due to weather conditions. Patterns for 1990 on the Hartsock farm (Fig. 1) illustrate the general pattern found in both years for total numbers of weeds found by herbicide/rotary hoeing treatment, over all species. Results for individual species had similar patterns, except that different species had different times of peak seedling emergence. Seedlings appeared in greatest numbers from mid-May to early June, with practically no seedlings appearing in April or after the last cultivation in late July (Fig. 1a). Patterns of seedling numbers were very similar for the banded herbicide and no herbicide treatments (Fig. 1a), although relative values for treatments varied among sample dates. Rotary hoeing and cultivation were effective in reducing weed numbers in all treatments. Discontinuities in lines in the figure reflect tillage operations between sample dates.

The number of weeds >2 cm (Fig. 1b) typically was greatest in late May and early June, with tillage, particularly cultivation, substantially reducing the number present.

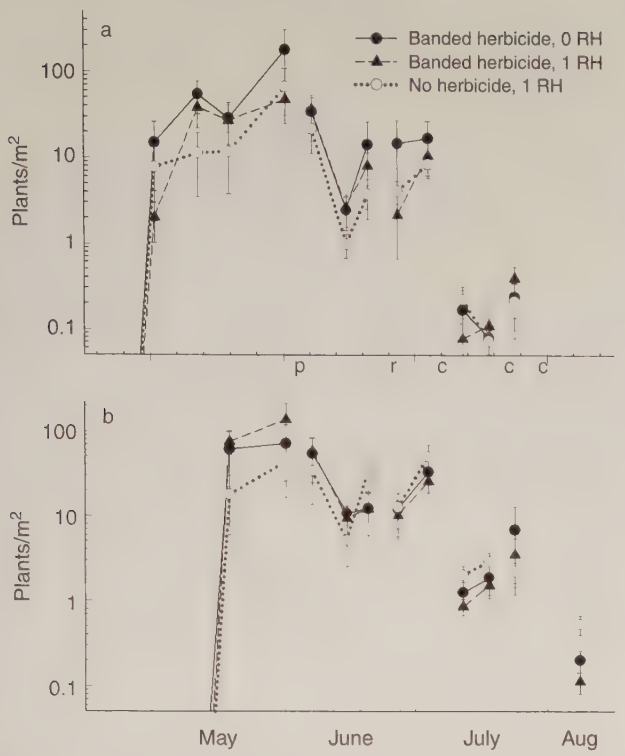

Figure 1. Mean total numbers of weeds (all species combined) present on plots with herbicide and no rotary hoeing (0 RH), with herbicide and one rotary hoeing (1 RH), or with no herbicide and one rotary hoeing at the Hartsock farm in 1990: (a) seedlings, (b) plants >2 cm tall. Bars indicate ± one standard error of the mean. Dates of field operations are indicated by letters (p, planting; r, rotary hoeing; c, cultivation). Data are plotted on log scales to accommodate extreme values.

Growth of plants previously categorized as seedlings also contributed to changes in number of weeds >2 cm after each tillage operation. Weeds >2 cm that were present late in the season arose almost entirely from seedlings appearing before the last cultivation, since practically no seedlings emerged after the last cultivation. In contrast, Forcella and Lindstrom[16] found that seed production from plants appearing after the last cultivation in a ridge-tillage system could contribute enough seeds to the soil seedbank to create substantial weed emergence the next year.

After all tillage operations were complete, weed populations in early August varied among farms in both years. Farms had a significant effect on foxtail species in both years and on Pennsylvania smartweed in 1990 (Table 5). Subsequently, values for the total over all species, a value dominated by foxtail species, and for the total over all broad-leaved species also showed a significant effect of farms in both years. Although there was substantial variation among farms in weed populations in both 1989 and 1990 (Tables 6 and 7), probably reflecting a combination of historical factors, spatial variation and unknown sources of variation, farm and herbicide treatment had no significant interaction in either year (Table 5). Over all farms, in 1989 herbicide treatment had a significant effect only for foxtail species and the total over all species (Table 5), and in 1990 herbicide/rotary hoeing treatment had a significant effect only for redroot pigweed (Table 5).

Since the experiments were conducted on commercial farms, no untreated, weedy plots were available for illustration of potential weed pressure on the sites. However, values of the highest number of weeds observed in June (e.g., 100–200 plants m^{-2} on the Hartsock farm, Fig. 1) imply that there were substantial weed densities and that the low values late in the season were due to successful control in all treatments, rather than lack of potential weeds. In 1989 (Table 6), tillage led to low numbers of total broad-leaved weeds and total weeds present on 1 August [<4600 ha^{-1} (<0.46 m^{-2}) total weeds on all farms]. In 1990 (Table 7), the total number of weeds was $<17{,}000$ ha^{-1} (<1.7 m^{-2}) on all farms. In both years, total broad-leaved weed populations in August were low [ranges of 382–2000 ha^{-1} (0.038–0.200 m^{-2}) in 1989 and 55–2900 ha^{-1} (0.0055–0.290 m^{-2}) in 1990]. These are within the range of the values of 0–1 m^{-2} often reported in the literature for good to excellent weed control[8,17–19], although the common practice of reporting weed numbers

Table 5. Analysis of variance results, over all farms, for numbers of weed plants on 1 August 1989 or 1 August 1990 and soybean yield in each year. Values are probability of a greater F value with an ANOVA model incorporating all the model terms listed (NS is given for $P>0.05$). The totals over broad-leaved species and over all species include all species found, not just foxtail, smartweed and pigweed.

Model term	Foxtail species	Pennsylvania smartweed	Redroot pigweed	Total broad-leaved species	Total all species	Soybean yield
1989						
Farm	0.02	NS	NS	0.01	0.02	0.0001
Block (Farm)	NS	NS	NS	NS	NS	0.04
Herbicide treatment	0.005	NS	NS	NS	0.02	NS
Farm × herbicide treatment	NS	NS	NS	NS	NS	NS
1990						
Farm	<0.0001	0.0001	NS	0.02	<0.0001	0.0001
Block (Farm)	0.001	NS	NS	NS	0.002	0.0001
Herbicide/rotary hoeing treatment	NS	NS	0.03	NS	NS	NS
Farm × herbicide/rotary hoeing treatment	NS	NS	NS	NS	NS	NS

Table 6. Weed populations on 1 August and soybean yield on three farms in Iowa in 1989.[1] All treatments also received rotary hoeing and cultivation (see Methods).

	Farm							
	Graaf		Grau		Hartsock		All farms	
	Mean	SE[2]	Mean	SE	Mean	SE	Mean	SE
Foxtail species (number ha^{-1})								
banded herbicide	902	373	217	99	829	291	649*	160
no herbicide	2510	805	658	255	3410	1000	2190*	480
Broad-leaved weeds (number ha^{-1})								
banded herbicide	1500	188	630	380	644	138	925	166
no herbicide	2000	609	382	228	1160	547	1180	300
Total weeds (number ha^{-1})								
banded herbicide	2400	443	847	371	1470	363	1570*	256
no herbicide	4510	1240	1040	373	4570	1480	3370*	719
Soybean yield (Mg ha^{-1})								
banded herbicide	2.20	0.064	3.04	0.016	2.39	0.026	2.54	0.168
no herbicide	2.32	0.054	2.98	0.019	2.44	0.028	2.57	0.138

[1] There was a significant effect of herbicide treatment, over all farms, for foxtail species and the total over all species.
[2] SE = standard error of the mean.

as integer values per m^2 makes comparisons particularly imprecise when values are less than 1 m^{-2}. It should also be recognized that the relationship between weed density and crop yield is variable with location, cropping system, etc.[20] None the less, a meaningful result here is that all treatments provided good to excellent weed control.

In 1989, soybean plant densities in mid-July were about 80% of the seeding density on all but the Graaf farm, where plant density was 53% of seeding density (Table 1). Over all farms, soybean yield in 1989 was significantly different among farms, but there was no significant difference between the banded herbicide and no herbicide treatments

Table 7. Weed populations on 1 August and soybean yield on three farms in Iowa in 1990.[1] All treatments also received cultivation (see Methods).

	Farm							
	Grau		Hartsock		Thompson		All farms	
	Mean	SE[2]	Mean	SE	Mean	SE	Mean	SE
Foxtail species (number ha^{-1})								
banded herbicide, 0 RH[3]	111	65	818	499	15,600	3900	5500	2124
banded herbicide, 1 RH	64	48	532	221	12,400	4610	4330	1240
no herbicide, 1 or 2 RH	3350	2020	3720	1660	9980	3480	5680	1490
Broad-leaved weeds (number ha^{-1})								
banded herbicide, 0 RH	440	434	1710	381	1290	429	1140	249
banded herbicide, 1 RH	55	38	1330	392	1670	801	1020	315
no herbicide, 1 or 2 RH	998	762	2900	1230	1660	713	1850	519
Total weeds (number ha^{-1})								
banded herbicide, 0 RH	551	438	2530	832	16,900	3910	6640	2130
banded herbicide, 1 RH	119	57	1860	587	14,100	5330	5360	2180
no herbicide, 1 or 2 RH	4350	2320	6620	1270	11,700	4100	7550	1620
Soybean yield (Mg ha^{-1})								
banded herbicide, 0 RH	2.67	0.147	2.07	0.008	2.97	0.093	2.57	0.206
banded herbicide, 1 RH	2.61	0.129	2.08	0.005	2.93	0.107	2.54	0.190
no herbicide, 1 or 2 RH	2.45	0.074	2.07	0.006	2.88	0.093	2.47	0.169

[1] There were no significant differences among herbicide treatments over all farms for mean values of any variable.
[2] SE = standard error of the mean.
[3] RH = rotary hoeing.

(Tables 5, 6). In 1990, soybean plant densities in early August were 45–74% of the seeding densities (Table 2). Soybean yield in 1990 again was significantly different among farms but was not significantly different among herbicide/rotary hoeing treatments, over all farms (Tables 5, 7). Mean within-farm soybean yields were 2.26, 3.01 and 2.42 Mg ha^{-1} on the Graaf, Grau and Hartsock farms, respectively, in 1989 and 2.58, 2.07 and 2.93 Mg ha^{-1} on the Grau, Hartsock and Thompson farms, respectively, in 1990. Treatments within a farm (Tables 6, 7) differed from the respective within-farm mean by a maximum of 0.5% to 5% on the different farms, with no significant treatment effects on yield.

Weed control results and soybean yield of the various treatments in the 2 years together indicate that rotary hoeing plus cultivation can be an effective substitute for banded herbicide plus cultivation in a ridge-tillage system. Buhler et al.[8] found that rotary hoeing plus cultivation could largely replace herbicide, although control was not as good with higher weed populations. Although not directly tested here, timing of rotary hoeing is an important factor in determining its efficacy[21]. Rotary hoeing is most effective in destroying weed seedlings that have germinated but not emerged and is still highly effective on emerged seedlings less than 7 mm tall, with little root development[21,22]. Here, weed populations in May and June were reduced by rotary hoeing in both years, and many unemerged weed seedlings likely were also destroyed. Annual weed species with small seeds that germinate from depths <5 cm are better controlled by rotary hoeing than are larger-seeded species that may emerge from greater depths[23]. Results here are consistent with that observation in that the major weed species present are relatively small-seeded[24], typically have greatest emergence from depths of a few centimeters[25,26], and apparently were well-controlled by rotary hoeing followed by cultivation. Rotary hoeing and cultivation may lose effectiveness in those conservation tillage systems in which a considerable amount of residue remains on the surface during the tillage operations[27], but burial of residue during ridge-tillage planting minimizes this problem.

In summary, patterns of weed population dynamics were similar in 1989 and 1990. In both years, herbicide banded in the row at planting and treatments without herbicide all produced low numbers of weeds (especially of broadleaved weeds) by August, with no significant difference in soybean yields, indicating that rotary hoeing plus cultivation were effective in replacing banded herbicide plus cultivation. Ridge-tillage can be effective in controlling weeds, and use of herbicide in ridge-tillage may be greatly reduced or even eliminated, thus reducing direct costs of herbicide application and potential environmental costs. However, such savings must be balanced against the costs and management demands of ridge-tillage. Furthermore, while ridge-tillage apparently has considerable potential as an alternative to herbicidal control of weeds, there remain questions as to how to optimize its efficiency. For example, the optimal timing, amount, direction, etc. of rotary hoeing need to be determined. Future research could address such questions, so that ridge-tillage can be optimized to balance degree of weed control, use of fossil fuels, management inputs and crop yield.

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Evaluation of weed control provided by three winter cereals in conservation-tillage soybean

Andrew J. Price[1,*], D. Wayne Reeves[2] and Michael G. Patterson[3]

[1]USDA-ARS, National Soil Dynamics Laboratory, Agriculture Research Service, United States Department of Agriculture, 411 South Donahue Drive, Auburn, AL 36832, USA.
[2]USDA-ARS, J. Phil Campbell, Sr. – Natural Resource Conservation Center, 1420 Experiment Station Road, Watkinsville, GA 30677, USA.
[3]Agronomy and Soils Department, Auburn University, 202 Funchess Hall, Auburn, AL 36830, USA.
*Corresponding author: aprice@ars.usda.gov

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Abstract

Information is needed on the role of cover crops as a weed control alternative due to the high adoption of conservation tillage in soybean [*Glycine max* (L.) Merr.] production. Field experiments were conducted from fall 1994 through fall 1997 in Alabama to evaluate three winter cereal cover crops in a high-residue conservation-tillage, soybean production system. Black oat (*Avena strigosa* Schreb.), rye (*Secale cereale* L.), and wheat (*Triticum aestivum* L.) were evaluated for their weed-suppressive characteristics compared to a winter fallow system. Three herbicide systems were utilized: no herbicide, a mixture of two pre-emergence (PRE) herbicides, or PRE plus post-emergence (POST) herbicides. The PRE system contained pendimethalin plus metribuzin. The PRE plus POST system contained pendimethalin plus a prepackage of metribuzin and chlorimuron ethyl applied PRE, followed by an additional chlorimuron ethyl POST application. No cover crop was effective in controlling weeds without a herbicide. However, when black oat or rye was utilized with only PRE herbicides, weed control was similar to the PRE plus POST input system. Thus, herbicide reductions may be attained by utilizing cover crops that provide weed suppression. Rye and black oat provided more effective weed control in the PRE only herbicide input system than wheat in conservation-tillage soybean. The winter fallow, PRE plus POST herbicide input system yielded significantly less soybean one out of three years when compared to systems that included a winter cover crop.

Key words: *Avena strigosa* Schreb., cover crops, *Secale cereale* L., *Triticum aestivum* L.

Introduction

Conservation-tillage systems are primarily used to address concerns about soil erosion, soil quality, and water availability[1–5]. The National Agricultural Statistics Service reported that in 2004, over 29 million hectares of soybean were planted in the US, an approximate 19% increase from 2003[6]. Soybean hectarage in conservation-tillage systems is estimated to be 50% in the US[7]. According to national statistics, herbicides were applied to 97% of soybean hectarage in 2001[7]. Practical alternatives to intensive use of herbicides for controlling weeds in soybean production offer economical as well as environmental benefits.

Cover crops in conservation-tillage offer many advantages, one of which is weed suppression through physical as well as chemical allelopathic effects[8,9]. Soybean following cereal rye (*Secale cereale* L.) or soft red winter wheat (*Triticum aestivum* L.) are the two most common winter crops in southeastern US soybean production. Both of these cover crops also contain allelopathic compounds that inhibit weed growth[10–13].

In southern Brazil, black oat (*Avena strigosa* Schreb.) is the predominate winter cover crop on millions of hectares of conservation-tilled soybean due in part to its weed suppressive capabilities[14]. Black oat's popularity as a winter cover crop in Brazil is largely due to its ability to control both annual grasses and small-seeded broadleaf

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weeds[15,16]. Use of black oat has recently been introduced in the southeastern US through a joint release between Auburn University and The Institute of Agronomy of Paraná, Brazil, and is currently marketed as 'SoilSaver black oat'[17]. In a greenhouse study, allelopathic compounds released from black oat have been shown to inhibit cotton root elongation 16% compared to rye when residue was mixed with soil[17]. However, in a field study where residue remained on the soil surface, cotton stand establishment was not affected by black oat, rye, or wheat winter covers, and cotton lint yield was higher in plots containing black oat residue compared to rye[17]. No other published research has been conducted evaluating black oat as a winter cover crop preceding row crop establishment in the US.

Typically, cooperative extension service recommendations in the southeastern US encourage growers to terminate non-harvested cereal winter covers before grain development, and possibly shred the residue, citing concerns for excessive residue interfering with planting operations or excessive moisture depletion[18–22]. Cooperative extension service recommendations also generally recommend waiting approximately 2 wk after desiccating cereal winter covers before planting soybean to avoid potential stand establishment problems resulting from planting into green residue and allelopathic effects on the following crop[20,21].

The Brazilian conservation-tillage system is based on terminating cover crops during early reproductive growth, by treating with glyphosate and mechanically rolling the covers, to form a dense mat of residue on the soil surface into which crop seeds are planted[14,23]. In the southeastern US, winter cereal cover crops reach anthesis and can be terminated in a timely fashion prior to the recommended planting windows for soybean. Ashford and Reeves[24] evaluated a mechanical roller-crimper as an alternative method for termination of black oat, rye, and wheat cover crops. Results showed that use of a roller-crimper plus glyphosate at 0.84 kg ha^{-1} a.i. at anthesis was as effective at the same growth stages as using glyphosate at 1.68 kg ha^{-1} a.i. for all covers evaluated. Few growers are currently utilizing roller-crimpers to manage cover crops; however, grower interest in this management technique exists due to its potential for reducing erosion and increasing infiltration and soil water storage[25].

While some research has evaluated weed-suppressive qualities of winter cover crops[8,10,13,14], few experiments have evaluated soybean response. Therefore, our objective was to evaluate weed control provided by black oat, rye, and wheat as winter cover crops within three herbicide input systems, compared to winter fallow, for conservation-tilled soybean using the Brazilian system of managing cover crops. Soybean yield was also evaluated for each cover and herbicide input system.

Materials and Methods

Field experiments were conducted from fall 1994 through fall 1997 at the Alabama Agricultural Experiment Station's Wiregrass Research and Extension Center, located near Headland, AL. The soil was a Dothan fine sandy loam (fine-loamy, siliceous, thermic Plinthic Paleudult). The experimental area had been in conservation tillage (strip-tillage consisting of subsoiling with approximately 30 cm of surface disturbance within the row) for the previous 8 yr and had a large population of Palmer amaranth (*Amaranthus palmeri* S. Wats.).

The experimental design was a strip-plot design with a factorial treatment arrangement and four replications of each treatment. Horizontal strips consisted of black oat, rye, wheat, or fallow. The seeding rate was 120 kg ha^{-1} for all cereal cover crops and 56 kg N ha^{-1} as ammonium nitrate was applied to cover crops in fall of 1994 and 1995 after establishment. No N was applied in 1996 due to an oversight. Cover crops were established utilizing a Great Plains® no-till drill (Great Plains Mfg., Inc., 1560 East North Street, Salina, KS 67401) in early November of 1994, 1995, and 1996 in the same location each year and were terminated 3 wk prior to planting soybean in early May each year with an application of glyphosate [*N*-(phosphonomethyl)-glycine] at 1.12 kg ha^{-1} a.i. utilizing a compressed CO_2 backpack sprayer delivering 140 liters ha^{-1} at 147 kPa. Biomass from black oat, rye, wheat, and fallow plots was measured immediately before glyphosate application in all years. The above-ground portion of each cover crop and weeds in the winter fallow plots were clipped from three randomly selected 0.25-m^2 sections in each plot, dried at 60°C for 72 h, and weighed.

Within 3 d following glyphosate application, covers were rolled with a mechanical roller-crimper as described by Ashford and Reeves[24] to flatten all residues on the soil surface. The soybean variety, 'Stonewall', was planted all three years with a Great Plains® no-till drill. In 1995, soil crusting resulted in a stand failure in the winter fallow plots and was replanted on May 23, 14 d after the first planting. Soybean seeds were planted at 336 kg ha^{-1}. Plots were 22–18 cm wide rows and 9.1 m long.

Vertical plots were herbicide input systems consisting of: no herbicide, pre-emergence (PRE) herbicides alone, or PRE plus post-emergence (POST) herbicides. The PRE system contained pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenena-amine] at 0.84 kg ha^{-1} a.i. plus metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)] at 0.43 kg ha^{-1} a.i. The PRE plus POST system contained pendimethalin at 0.84 kg ha^{-1} a.i. plus a prepackage of metribuzin at 0.39 kg ha^{-1} a.i. and chlorimuron ethyl {ethyl 2-[[[[(4-chloro-6-methoxypyrimidin-2-yl)amino]carbonyl]amino]sulfonyl]benzoate} at 0.06 kg ha^{-1} a.i. applied PRE, followed by an additional chlorimuron ethyl POST application at 8.75 g ha^{-1} a.i.

In fall 1994, because the site had a well-developed hardpan, the experimental area was subsoiled prior to planting with a bent-leg paratill (Bigham Brothers Inc., 705 East Slaton Dr., Lubbock, TX 79404) 2 wk prior to planting

the winter cover and again in 1996, 2 wk prior to planting soybean.

Weed control was determined by visual ratings (0% = no control, 100% = complete control) early in the season [30 d after planting (DAP)] and late in the season (51 and 80 DAP). Only ratings determined at 51 DAP are reported. All weed species present at both ratings were evaluated for control, as a reduction in total above-ground biomass resulting from both reduced emergence and growth, and the combined average for each rating and treatment was calculated.

Alabama Cooperative Extension System recommendations were used for insect control and nutrient management. Soybean yield was determined by machine-harvesting each plot with a small plot combine.

All data were subjected to analysis of variance (ANOVA) using the general linear models procedure in SAS (SAS 1998) to evaluate the effect of a three (herbicide input level) by four (winter cover) factorial treatment arrangement. Herbicide input levels and winter covers were considered fixed effects, while year effects were considered random variables. Non-transformed data for visual evaluations were presented because arcsine square root transformation did not affect data interpretation. Means for appropriate main effects and interactions were separated using Fisher's protected LSD test at $P = 0.1$. Where interactions occurred, data were presented separately and where interactions did not occur, data were combined.

Results and Discussion

Cover crop biomass

There was a year by treatment effect; therefore, results are presented by year. In 1995, residue production was similar for all winter cereal covers, averaging 5230 kg ha^{-1}. Winter weeds produced 1410 kg ha^{-1} in fallow plots. Dominant winter weeds in the fallow system all 3 years were cutleaf eveningprimrose (*Oenothera laciniata* Hill) and common chickweed [*Stellaria media* (L.) Vill.]. The severe winter of 1995–1996 resulted in differences in residue production by the covers. Biomass averaged 6250, 4370, 1320, and 870 kg ha^{-1} for rye, wheat, black oat, and winter fallow, respectively, in 1996. The minimum night-time temperature from November 1 through March 31 was below 0°C for 56 nights in 1995–1996 (−13°C lowest temperature) compared to 33 nights in 1994–1995 (−8°C lowest temperature) and 26 nights in 1996–1997 (−10°C lowest temperature). In 1997, residue production was similar for rye (2840 kg ha^{-1}) and black oat (2770 kg ha^{-1}); however, wheat produced less biomass (1600 kg ha^{-1}) than earlier years because nitrogen fertilizer was not applied to winter covers due to an oversight in 1996. Winter weeds produced 770 kg ha^{-1} in fallow plots. Yenish et al.[13] reported that rye planted into a sandy loam soil resulted in biomass ranging from 4540 to 5140 kg ha^{-1} in North Carolina. Bauer and Reeves[26] reported an average biomass of 5300, 2980, and 3010 kg ha^{-1} for rye, black oat, and wheat, respectively, planted into a loamy sand soil in South Carolina. Ashford and Reeves[24] reported higher biomass for rye, black oat, and wheat in east-central Alabama when evaluating effectiveness of a roller-crimper for cover crop desiccation. They also reported that averaged over 2 years, biomass was 10,100, 9700 and 9100 kg ha^{-1} for rye, black oat, and wheat, respectively. The decrease in black oat biomass was attributed to freeze injury in 1999, when temperatures were as low as −10°C[24]. In all years, residue disturbance was minimal and residue formed a dense mat over the soil surface, as in the Brazilian conservation tillage-cover crop management system, with exception of the fallow plot treatment.

Weed control

There was a year by treatment effect; therefore, results are presented by year. Grasses {primarily large crabgrass [*Digitaria sanguinalis* (L.) Scop.] and Texas panicum (*Panicum texanum* Buckl.)}, nutsedges [(*Cyperus esculentus* L.) and (*C. rotundus* L.)], sicklepod (*Senna obtusifolia* L.), and Palmer amaranth were the dominant weed species present during all three experimental years. In 1995, there was a significant cover by herbicide input level interaction. Without herbicide, all winter covers provided increased control compared to winter fallow (Table 1). Also, without herbicide, black oat and rye provided more effective weed control (based on visual ratings and weed biomass) than wheat (86 and 83%, respectively, versus 61%) in 1995, but in 1996, rye gave greater visual control than black oat and wheat (58% versus 22 and 29%, respectively) due to winter kill of black oat and the documented lower allelopathic potential of wheat[9,12]. In 1997, black oat and rye provided similar levels of weed control (73–69%) without herbicide, providing increased weed control compared to winter wheat or fallow. In all years, both rye and black oat covers, and in one year wheat cover, in combination with PRE herbicides provided similar weed control compared to high input herbicide systems. Yenish et al.[13] reported increased short-term weed control utilizing a non-rolled rye cover crop in no-till corn (*Zea mays* L.), but not season-long control. Reddy[27] reported that rye reduced the total weed density 27% in no-till soybean 6 wk after planting.

Soybean yield

There was a year by treatment effect; therefore, results are presented by year. Averaged across winter covers, soybean yields were 5913 and 6249 kg ha^{-1} for the high herbicide input system and the low input system, respectively, in 1995 (Table 2). Without herbicide, yields following black oat or rye covers (6047 kg ha^{-1}) were higher than the high input fallow treatment (4031 kg ha^{-1}). There were no significant yield differences between cover crops within herbicide input systems, or between the herbicide input system within a cover crop. Yield potential was high due to adequate rainfall throughout the growing season.

Table 1. Weed control[1] affected by cover crop and herbicide system for 3 years at the Alabama Agricultural Experiment Station's Wiregrass Research and Extension Center in Headland, AL.

	1995[2]				1996[3]				1997[4]			
	Herbicide input system[5]				Herbicide input system				Herbicide input system			
Cover crop	High	Low	None	*Mean*	High	Low	None	*Mean*	High	Low	None	*Mean*
	Weed control (%)											
Black oat	95	95	86	*92*	89	86	22	*66*	95	91	73	*86*
Fallow	92	85	29	*69*	91	82	16	*63*	95	93	59	*82*
Rye	95	95	83	*91*	91	88	58	*79*	95	92	69	*85*
Wheat	95	91	61	*82*	93	84	29	*69*	95	91	61	*82*
Mean	*94*	*92*	*65*		*91*	*85*	*31*		*95*	*92*	*65*	

[1] Averaged over Palmer amaranth, sicklepod, annual grasses, and nutsedges.
[2] 1995 $LSD_{(0.10)}$ for cover crop = 8; for herbicide level = 8; for cover crop within herbicide level interaction = 12; for herbicide level within cover crop interaction = 11.
[3] 1996 $LSD_{(0.10)}$ for cover crop = 4; for herbicide level = 6; for cover crop within herbicide level interaction = 7; for herbicide level within cover crop interaction = 9.
[4] 1997 $LSD_{(0.10)}$ for cover crop = 4; for herbicide level = 4; for cover crop within herbicide level interaction = 7; for herbicide level within cover crop interaction = 8.
[5] Herbicide input systems consisted of: no herbicide, PRE herbicides alone, or PRE plus POST herbicides. The PRE system contained pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenena-amine] at 0.84 kg ha^{-1} a.i. plus metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)] at 0.43 kg ha^{-1} a.i. The PRE plus POST system contained pendimethalin at 0.84 kg ha^{-1} a.i. plus a prepackage of metribuzin at 0.39 kg ha^{-1} a.i. and chlorimuron ethyl {ethyl 2-[[[[(4-chloro-6-methoxypyrimidin-2-yl)amino]carbonyl]amino]sulfonyl]benzoate} at 0.06 kg ha^{-1} a.i. applied PRE, followed by an additional chlorimuron ethyl POST application at 8.75 g ha^{-1} a.i.

Table 2. Soybean yields as affected by cover crop and herbicide system for three years at the Alabama Agricultural Experiment Station's Wiregrass Research and Extension Center in Headland, AL.

	1995[1]				1996[2]				1997[3]			
	Herbicide input system[4]				Herbicide input system				Herbicide input system			
Cover crop	High	Low	None	*Mean*	High	Low	None	*Mean*	High	Low	None	*Mean*
	Soybean yield (kg ha^{-1})											
Black oat	6719	7391	6047	*6719*	8063	8735	2688	*6517*	2016	2016	2016	*2016*
Fallow	4031	4031	1344	*3158*	8735	6719	2688	*6041*	2016	2016	1344	*1814*
Rye	6047	6719	6047	*6249*	8735	8735	6047	*7861*	2016	2016	1344	*1814*
Wheat	6719	6719	4703	*6047*	8735	8063	4031	*6921*	2688	2016	1344	*2016*
Mean	*5913*	*6249*	*4569*		*8600*	*8063*	*3897*		*2217*	*2016*	*1545*	

[1] 1995 $LSD_{(0.10)}$ for cover crop = 1344; for herbicide level = 1075; for cover crop within herbicide level interaction = NS, non-significant; for herbicide level within cover crop interaction = NS.
[2] 1996 $LSD_{(0.10)}$ for cover crop = 605; for herbicide level = 739; for cover crop within herbicide level interaction = 1344; for herbicide level within cover crop interaction = 1411.
[3] 1997 $LSD_{(0.10)}$ for cover crop = 134; for herbicide level = 134; for cover crop within herbicide level interaction = 202; for herbicide level within cover crop interaction = 202.
[4] Herbicide input systems consisted of: no herbicide, PRE herbicides alone, or PRE plus POST herbicides. The PRE system contained pendimethalin at 0.84 kg ha^{-1} a.i. plus metribuzin at 0.43 kg ha^{-1} a.i. The PRE plus POST system contained pendimethalin at 0.84 kg ha^{-1} a.i. plus a prepackage of metribuzin at 0.39 kg ha^{-1} a.i. and chlorimuron ethyl at 0.06 kg ha^{-1} a.i. applied PRE, followed by an additional chlorimuron ethyl POST application at 8.75 g ha^{-1} a.i.

In 1996, yields averaged across winter covers were 3897, 8063, and 8600 kg ha^{-1} with no, low, and high herbicide input systems, respectively. Averaged across herbicide input systems, winter covers affected soybean yields in 1996, averaging 6041, 6517, 6921, and 7861 kg ha^{-1} for fallow, black oat, wheat, and rye, respectively (Table 2). Soybean following rye yielded more than fallow, wheat, and black oat covers. Soybean yields were similar following black oat and wheat with high or low herbicide inputs, despite black oat being winter-killed and only producing 1320 kg ha^{-1} dry biomass, compared to 4370 kg ha^{-1} biomass from wheat. There was a significant interaction between cover crops and herbicide input system; soybean yield with the low input system following rye

(8735 kg ha^{-1}), black oat (8735 kg ha^{-1}), and wheat (8063 kg ha^{-1}) was greater than that following the winter fallow system (6719 kg ha^{-1}). In the no-herbicide system, soybean yield following rye yielded highest (6047 kg ha^{-1}) compared to following wheat (4031 kg ha^{-1}), which was higher than black oat or winter fallow (2688 kg ha^{-1}). There was also a significant interaction between herbicide input levels within each cover crop. Soybean following black oat and rye had similar yields in high and low herbicide input systems, while soybean following winter fallow or wheat provided less yield. However, with no herbicide input, only soybean following the rye cover provided the highest yield. Compared to 1995, yield potential was again high due to above-average rainfall throughout the growing season.

In 1997, a relatively dry fall occurred during soybean development, resulting in lower soybean yields. Yields averaged across winter covers were 1545, 2016, and 2217 kg ha^{-1} with no, low, and high herbicide input programs, respectively (Table 2). The no herbicide system yielded less than both the low and high input systems, but unlike 1995 and 1996, there was a yield benefit from the high herbicide system compared to the low input system. The reduced yield potential as a result of the dry fall enhanced the yield response between the high and low input systems. The failure to apply N fertilizer to the cover crops in 1997 reduced cover crop biomass to only 2840 kg ha^{-1} for rye, 2770 kg ha^{-1} for black oat, and 1600 kg ha^{-1} for wheat, values 31–53% of the maximum achieved in other years by these cover crops. Despite this, winter covers, averaged over herbicide input systems, affected soybean yields in 1997, averaging 1814, 2016, 2016, and 1814 kg ha^{-1} for fallow, black oat, wheat, and rye, respectively. The fallow and rye covers yielded less than black oat and wheat covers. There was a significant interaction between cover crops and herbicide input system. Soybean yield with the high input system following wheat (2688 kg ha^{-1}) was greater than that following black oat (2016 kg ha^{-1}), rye (2016 kg ha^{-1}), or winter fallow system (2016 kg ha^{-1}). In the no-herbicide system, soybean yield following black oat yielded highest (2016 kg ha^{-1}) compared to following wheat (1344 kg ha^{-1}), rye (1344 kg ha^{-1}), or winter fallow (1344 kg ha^{-1}). There was also a significant interaction between herbicide input levels within each cover crop. Soybean following black oat provided similar yields in high, low, and no herbicide input systems, while soybean following winter fallow, rye, or wheat provided reduced yield in low and no herbicide input systems.

There was a strong weed control benefit for planting conservation-tilled soybean using the Brazilian cover crop management system; i.e., cover crops grown to produce large amounts (>4480 kg ha^{-1}) of residue rolled to form a dense mat on the soil surface[14,23]. Our results suggest that rye and black oat cover crops are more effective in no herbicide input systems than wheat for weed control in conservation-tilled soybean. In two of three years, black oat biomass was equivalent to rye, and equivalent or greater than wheat. However, inferior cold tolerance of black oat compared to rye may limit its zone of utilization. Our results also agree with the literature that reports that rye is more weed-suppressive than wheat[9]. Systems that did not include herbicides were not effective at controlling weeds adequately the entire season and resulted in substantial yield losses. However, when black oat was utilized along with PRE herbicides, similar weed control to the high input system was attained.

Results also indicate a potential yield benefit for planting conservation-tilled soybean using the Brazilian cover crop management system, compared to a winter fallow system. The winter fallow, high herbicide input system yielded significantly less soybean one out of three years, compared to systems that included a winter cover crop. Also, soybean in the winter fallow plots were replanted in 1995 due to soil crusting, highlighting another advantage provided by the winter cover crops we evaluated. The yield benefit was more apparent in low herbicide input systems where the winter fallow yielded significantly less soybean two out of three years, compared to systems that included a winter cover crop. We attribute the observed increase in yield to many factors, mainly the observed decrease in weed competition, as well as other non-measured but known benefits of conservation-tillage systems, including increased water infiltration, reduced water evaporation from the soil, and increased soil quality[28].

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Effects of green manure use on sweet corn root length density under reduced tillage conditions

C.M. Cherr[1], L. Avila[1], J.M.S. Scholberg[1,*] and R. McSorley[2]
[1]Department of Agronomy, and [2]Department of Entomology and Nematology, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611, USA.

*Corresponding author: jmscholberg@ifas.ufl.edu

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Abstract

A green manure (GM) is a crop grown primarily as a nutrient source and soil amendment for subsequent crops. In environments such as Florida, combined use of GM and reduced tillage may improve soil water and nutrient retention and reduce potential groundwater pollution. In the first 3 years of a long-term experiment, use of GM in a reduced-tillage system on a sandy Florida soil benefited the season-long growth of sweet corn (*Zea mays* L. var. Rugosa) much more than final ear yields. To help understand these patterns, we evaluated response of sweet corn roots when in rotation with GM of sunn hemp (*Crotalaria juncea* L.; summer) and cahaba white vetch (*Vicia sativa* L.; winter 2002–2003) and a multi-species mixture of hairy vetch (*V. villosa* Roth.) and cereal rye (*Secale cereale* L.; winter 2003–2004). Treatments included sweet corn with combinations of 0 or 133 kg chemical N ha^{-1} (as NH_4NO_3) and with or without GM. A highly fertilized treatment (267 kg chemical N ha^{-1}) without GM was also included. Soil cores were sampled from three depths (0–15, 15–30 and 30–60 cm) both between and within corn rows. Data from two experiments showed that use of GM increased sampled corn root length density (RLD) by 44–54%, although only within the upper 15 cm of soil in one of the two experiments. Corn following GM plus 133 kg chemical N ha^{-1} produced up to 44% greater RLD than corn with 267 kg chemical N ha^{-1}. Sampled RLD decreased with distance away from corn plants (from in-row to between-row positions, and from shallow to deeper depth), with roughly 85–95% of sampled RLD existing in the top 30 cm of soil across all treatments. During the 2004 experiment, we found that broadcast, as opposed to banded (placed along corn row only), chemical N application resulted in more even distribution of corn RLD between in-row and between-row positions during late-season without regard to GM crop. Although GM permitted optimal sweet corn growth with a 50% reduction in chemical N application, ear fill during the final 1–2 weeks before harvest may have been reduced in GM treatments. GM effects on the amount and spatial distribution of sweet corn RLD may help explain these trends. Provision of greater N from GM residues and/or altered distribution of supplementary chemical N and irrigation may be required to achieve greater ear yield benefit from GM.

Key words: green manure, root length density, sweet corn, reduced tillage, organic amendments, root distribution

Introduction and Literature Review

Due to coarse-textured soil and high temperatures and rainfall, many Florida soils contain little organic matter (less than 10 g kg^{-1}) and have poor water and nutrient retention[1]. Concern exists over potential groundwater nitrate pollution from Florida agricultural systems[2], especially for crops such as sweet corn for which high rates of nitrogen (N) fertilizer are recommended[3].

Legumes utilized as green manure (GM) may provide on-farm sources of organic N. Reduced tillage may also be desirable to slow decomposition of GM residues and increase soil organic matter levels over the long-term in the Florida environment[4]. A long-term study of such reduced tillage, GM-based cropping systems was initiated at UF's Plant Science Research and Education Unit in 2001. However, while short-term effects of GM permitted optimal sweet corn growth with a 50% reduction in chemical N application, ear fill during the final 1–2 weeks before harvest may have been reduced in GM treatments[5]. If patterns in root growth and distribution are associated with these trends, key changes in water and nutrient

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management may better enable sweet corn producers to transition to reduced-tillage, GM-based systems. However, very little data exist for root behavior of sweet corn under such conditions.

Root length density (RLD)—defined as length of roots per unit volume of soil—may give some indication of plant response to environmental factors[6]. Increased RLD in response to increased nutrient and water availability, a phenomenon known as *root proliferation*, may reflect greater water and nutrient uptake potential[7]. However, root water and nutrient uptake may be dictated by a complex interplay of RLD, soil water and nutrient availability, root age, plant stress and soil aeration status[6,8]. Additionally, soil water and nutrient status may change more rapidly (hours to days) than RLD can respond (days to weeks). Effective rooting depth may limit plant access to water and nutrients as they move down the soil profile. Working with conventional tillage on a silty clay loam in Nebraska, Eghball and Maranville[9] found that a deeply rooted (to 0.9 m) field corn (*Zea mays* var. L) had a greater yield response than shallow-rooted varieties when irrigation led to deeper water infiltration, and that moderate N and water stress increased RLD uniformly throughout the soil profile while severe water and N stress reduced RLD. In a greenhouse study with a potting soil and sand mixture, Eghball et al.[10] removed entire corn root systems and found 52.7, 37.6 and 9.7% of root length in the 0–0.3, 0.3–0.6 and 0.6–0.9 m depths.

Due to different nutrient release characteristics and effects on soil water, temperature, and biota, root growth patterns may be markedly different following GM compared to chemical fertilizer. Because their N release is driven by decomposition, GM may represent a source of slow-release N. Spatial distribution of GM residue may be heterogeneous, creating localized areas of N release and other GM-mediated impacts[11]. GMs may have effects on soil moisture transfers, temperature and populations of root-parasitizing organisms such as nematodes[12,13] which could also affect root growth. To help explain higher ear yields from corn in rotation with GM and supplemented with animal manure compared to monocropped corn with conventional inputs, Goldstein[14] studied field corn roots on a fine-textured soil in Wisconsin under conventional tillage. In this study, corn following GM and animal manure maintained healthier roots. Pallant et al.[15] found greater RLD in the upper 30 cm of soil for corn in rotation with GM. According to Nickel et al.[16], RLD for corn grown in rotation with soybean (*Glycine max*) tends to be higher than that for corn grown in monoculture even with high input use. In a conventional tillage system, Nickel et al.[16] found greater RLD for monoculture corn in shallow soil depths (upper 12.5 cm) during early season while corn in rotation with soybean showed greater RLD in deeper soil layers (between 12.5 and 50 cm) during mid- to late-season. Pallant et al.[15] also found that increases in soil organic matter significantly increased corn RLD on two of four sample dates.

For potato (*Solanum tuberosum* L.), Opena and Porter[17] report that organic amendments (compost plus beef cattle manure) significantly increased RLD in the 0–30 cm plow layer and did not change relative distribution of roots by depth (~85% of RLD in 0–30 cm layer). However, Thorup-Kristensen and van der Boogaard[18] found that surface applying increased amounts of high-N GM residue reduced carrot (*Daucus carota* L.) root proliferation in the upper 1 m of soil and shifted roots closer to the plant.

We investigated a GM-based rotation of summer planted sunn hemp (SH) followed by a winter legume (L) of blue lupin (*Lupinus angustifolius* L., winter 2001–2002), cahaba white vetch (winter 2002–2003), and a hairy vetch plus rye mixture (winter 2003–2004) as an N source for sweet corn under reduced tillage. In these studies, use of summer plus winter GM produced a cumulative 12–15 Mg dry matter ha^{-1} and up to 240 kg N ha^{-1} annually. Details of GM growth and decomposition patterns are discussed by Cherr[5], as are yield responses of sweet corn to the GM sequence and to the component GM crops alone (summer GM only and winter GM only). To better explain growth and final ear yield patterns for corn with GM, we conducted two root studies of selected treatments. In both experiments, we hypothesized that use of summer plus winter GM would increase overall sweet corn RLD, that sweet corn RLD would be redistributed nearer to the GM residue (in this case, near the surface as we used reduced tillage), and that corn with a high chemical N rate (267 kg NH_4NO_3-N ha^{-1}) would show greater RLD than corn at lower N rates (0 or 133 kg NH_4NO_3-N ha^{-1}) with or without GM. In the 2004 experiment, we also evaluated the effect of chemical N application method on root length distribution, hypothesizing that broadcast application would lead to more even distribution of roots than banded application.

Materials and Methods

Overall set-up and design

Research was conducted at the Plant Science Research and Education Unit near Citra, Florida (University of Florida, Gainesville). Candler fine sand (Typic Quarzipsamments, hyperthermic, uncoated) and Lake fine sand (Typic Quarzipsamments, hyperthermic, coated) were the dominant soil types (typically, both are >95% sand in upper 1–2 m of soil; see reference [1]). The field had been planted with peanut (*Arachis hypogea* L.) 1 year earlier, but previously had remained in long-term grass pasture. The overall project consisted of 15 treatments repeated four times in a randomized complete block design. A complete description of treatments and timeline of events is provided elsewhere[5]. After initial field roto-tilling in 2002, all crops were planted with zero or reduced tillage.

2003 Experiment

Root growth analysis utilized five treatments. GM treatments consisted of sweet corn (spring 2002 and 2003) in

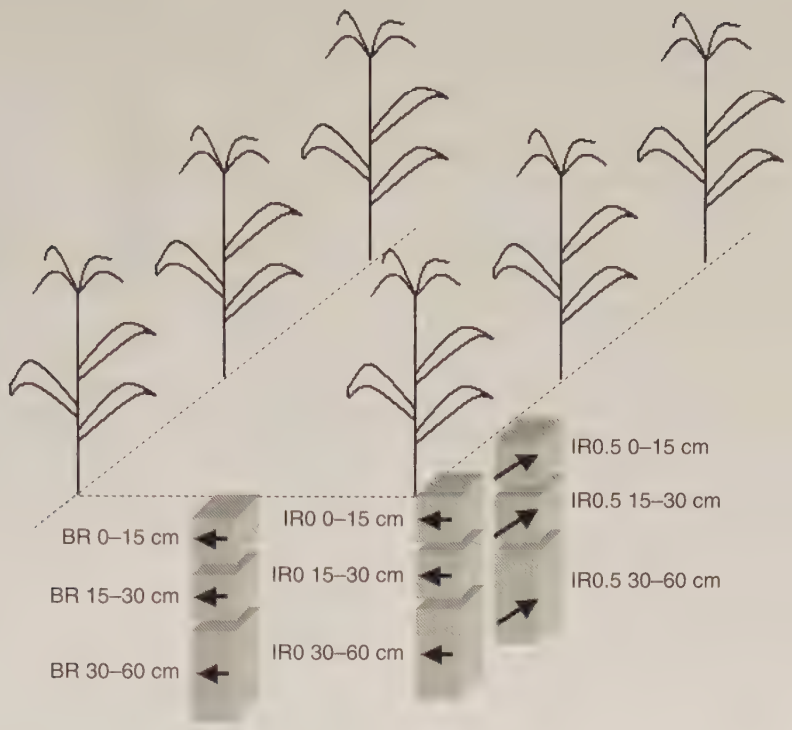

Figure 1. Name, location and relative volume of root core samples in the 2003 experiment (arrows indicate name). Sampling in the 2004 experiment was identical except no cores were taken from IR0.5 at any depth.

rotation with a GM sequence of SH (summer 2001 and 2002), blue lupin (winter 2001–2002), and Cahaba white vetch (winter 2002–2003), with 0 or 133 kg inorganic N ha^{-1} applied to corn (GM 0N and GM 133N, respectively). Conventional treatments consisted of sweet corn with 0, 133, or 267 kg inorganic N ha^{-1} applied (Conv 0N, Conv 133N, Conv 267N). Details of GM planting, growth and management are provided elsewhere[5]. In GM 133N, dry matter additions from all crop and weed residues (including corn stover) during the first 2 years of the study averaged roughly 20 Mg ha^{-1} yr^{-1}. During the same period, dry matter additions in Conv 133N and Conv 267N both averaged roughly 9 Mg ha^{-1} yr^{-1}. Residues were mown prior to corn planting and after corn harvest. In both 2002 and 2003, sweet corn (variety GS 0966; Syngenta; Basel, Switzerland) was planted in April with in-row spacing of 18 cm and between-row spacing of 75 cm. In 2003, corn emerged on April 15, 2003. All chemical N was applied as NH_4NO_3 in three equal split applications at 0, 3 and 5 weeks after emergence (WAE). Chemical N was band applied to corn rows by hand. Samplings of these treatments for RLD analysis in the 2003 experiment took place during the second year of sweet corn (2003).

Using a 5-cm soil auger (Forestry Suppliers, Inc; Jackson, MS) of known volume, soil cores were extracted at 3, 5 and 8 WAE of sweet corn. In each plot, soil was extracted from three different depths: 0–15; 15–30 and 30–60 cm; and in three different surface positions: in-row and immediately adjacent to a corn plant (IR0); in-row and halfway between two corn plants (IR0.5); and between-row (halfway between two corn rows; BR), giving nine unique locations (Fig. 1). Soil extraction was conducted away from border areas and near plants representative of the plot in both size and spacing. Soil cores were washed in a grain sieve with pores 4.5 mm in diameter. Although root hairs could not be accounted for, this grain sieve satisfactorily retained visible roots which were then separated from debris. RLD for each core was then determined with Winrhizo (Regent Instruments; Quebec City, Canada) software and hardware. Results were transferred to MS Excel (Microsoft Corporation, Los Angeles, CA) for organization and graphical analysis.

To test the effects of GM amendment and chemical N rate on root length and distribution, a balanced ANOVA was run for sample results from GM 0N, GM 133N, Conv 0N and Conv 133N using SAS software package (Statistical Analysis Systems; Cary, NC). Sample RLDs were log transformed by $\log_{10}(x+1)$ before ANOVA to maintain homoscedasticity. RLD was modeled as a function of sample date, N rate, GM use, depth, position, all possible interactions of these main effects and block. Where interaction terms were significant ($\alpha = 0.05$), separate ANOVAs were run to compare levels of one interacting variable within specific levels of the other interacting variable(s). Non-interacting variables (except block) were not included in the interaction model statements. Comparisons of means were always made with Duncan's multiple range test. A similar ANOVA was also conducted with sample data expressed on a relative basis (as a fraction of the total root length sampled from the plot on the corresponding

date), permitting comparisons of root distribution between treatments regardless of absolute size. However, because trends were similar to that on a density basis, results of an ANOVA on relative root length basis are not shown.

To compare root length and distribution patterns of these treatments to high-fertilized, high-producing corn, pairwise contrasts of Conv 267N were made with each of the other treatments. A complete ANOVA was conducted on RLD as a function of treatment (all treatments, including Conv 267N), sample date, position, depth, all interactions of these main effects and block. Analyses of significant interactions were identical to that described above.

Transducing tensiometers (model 'R' irrometers; Spectrum Technologies; Plainfield, IL) were installed in selected plots along with suction lysimeters to monitor N leaching. Although suction lysimeters yielded no information, data from transducing tensiometers buried at 15, 60 and 90 cm in GM 133N and Conv 200N are reported here. Data from tensiometers were recorded continuously by Watchdog dataloggers (Spectrum Technologies; Plainfield, IL). Treatment Conv 200N was not sampled for root cores.

2004 Experiment

Based on results of the 2003 experiment, a second study was conducted at the same field site in 2004 using three treatments: GM 133N, Conv 133N and Conv 267N. Crop rotation remained similar to previous years, with SH GM planted in summer 2003, a winter GM of hairy vetch plus rye mixture in winter 2003–2004, and sweet corn (same variety as in 2003) planted in spring 2004 using identical equipment and spacing as in previous years. Combined GM and weed production in GM 133N amounted to roughly 17 Mg ha^{-1} (Avila, 2004, unpublished data). Based on previous years' results, chemical N was distributed at 20% at 0 WAE, and 40% at 5 and 8 WAE each. Root cores were extracted at 4, 6 and 9 WAE from two surface positions: IR, halfway between plants and BR, halfway between plants. Otherwise, field and laboratory procedures were identical to the 2003 experiment.

ANOVA was conducted similar to that involving all treatments in the 2003 experiment. Pairwise contrasts between sampled treatments were made again in the 2004 experiment to evaluate GM effects on corn RLD (GM 133N versus Conv 133N) and compare GM 133N and Conv 133N to highly fertilized corn (Conv 267N). To evaluate effects on RLD and distribution of broadcasting, as compared to banding, of chemical fertilizer, chemical N was broadcast applied in sub-plot sections of 8.4 m^2 in GM 133N and Conv 133N treatments. In main plots, chemical N was applied identically as in the 2003 experiment (banded). Samples from broadcast sub-plots were taken at 9 WAE only. RLD data from these sub-plots, and from (banded) main plots of GM 133N and Conv 133N at 9 WAE were modeled as a function of GM level, N application method, position, depth, all interactions of these main effects and block.

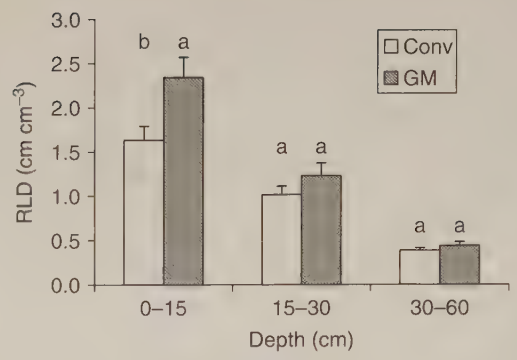

Figure 2. Effect of green manure (GM) and conventional (Conv) treatments on sampled sweet corn RLD by depth over all sampled positions and dates in the 2003 experiment. Error bars reflect standard errors; lower case letters reflect ANOVA differences within sample depth, $P \leqslant 0.05$.

Results

2003 Experiment

RLD and relative root length distribution. Over the season, RLD for the sampled volume in the upper 0–60 cm soil layer remained within one order of magnitude in all treatments, from 0.17 to 1.65 cm cm^{-3}, consistent with other studies[14–16]. Use of GM increased corn RLD in the upper (0–15 cm) soil layer by 44%, with smaller increases in deeper layers (15–30 and 30–60 cm) that were non-significant (Fig. 2). A three-way interaction between sample date, chemical N rate and GM level (Table 1; sub-effects not shown) showed that GM use increased RLD throughout the entire 0–60 cm soil layer only during late-season when no N (0N) was applied (data not shown). Moreover, conventional corn showed greater RLD response to chemical N during late-season growth than GM amended corn (data not shown).

Across all positions or depths, corn RLD increased significantly only from 3 to 5 WAE. Exception to this occurred at 30–60 cm depth, where increase continued from 5 to 8 WAE. Additionally, RLD increase in the BR position from 3 to 5 WAE appeared less than in either IR position (Table 2). RLD decreased from IRs (IR0, IR0.5) to BR positions but did not differ between IR0 and IR0.5 positions. In the BR position, RLD at 15–30 and 30–60 cm depths were quite low and did not differ significantly from each other (Table 2). Increasing chemical N rate from 0 to 133 kg N ha^{-1} significantly increased RLD throughout the IR, but not BR, positions, perhaps due to the banded application of N. Across all depths, this increase of chemical N rate increased corn RLD, although increase in the 30–60 cm layer was smallest and may have become significant only when the individual (sub-effect) ANOVA was run (Table 2).

Statistical patterns of relative root length distribution were similar to those of absolute RLD. For all treatments throughout the season, relative root length sampled remained numerically greatest in the IR0 0–15 cm location

Table 1. Significance of GM, N rate, date, position, depth and sub-effects when constituting linear model for sampled RLD in the 2003 experiment.

Model term	Probability (P)
Main effects	
Date	< 0.0001
Pos	< 0.0001
Depth	< 0.0001
N rate	< 0.0001
GM	< 0.0001
Two-way interactions	
Date × Pos	< 0.0001[1]
Date × Depth	< 0.0001[1]
Pos × Depth	< 0.0001[1]
Date × N rate	< 0.0001
N rate × Pos	0.0001[1]
N rate × Depth	< 0.0001[1]
Date × GM	NS
GM × Pos	NS
GM × Depth	0.0007[2]
N rate × GM	NS
Three-way interactions	
Date × Pos × Depth	NS
Date × N rate × Pos	NS
Date × N rate × Depth	NS
N rate × Pos × Depth	NS
Date × GM × Pos	NS
Date × GM × Depth	NS
GM × Pos × Depth	NS
Date × N rate × GM	0.0137[3]
N rate × GM × Pos	NS
N rate × GM × Depth	NS
Four-way interactions	
Date × N rate × Pos × Depth	NS
Date × GM × Pos × Depth	NS
Date × N rate × GM × Pos	NS
Date × N rate × GM × Depth	NS
N rate × GM × Pos × Depth	NS
Five-way interaction	
Date × N rate × GM × Pos × Depth	NS

Pos, position; N rate, chemical N application level; GM, GM level; NS, not significant at the $P \leqslant 0.05$ level.
[1] See Table 2.
[2] See Figure 2.
[3] Not shown (see text).

(23–27%), roughly half or more (up to 55%) of sampled root length was always in the 0–15 cm layer, with the upper 30 cm containing roughly 85% of sampled root length (data not shown). These results are similar to the findings reported by Eghball et al.[10] RLD decreased exponentially with increasing depth from the surface in nearly all plots in all sample dates.

Although ANOVA of all sampled treatments (including Conv 267N) indicated significant two-way interactions of treatment with date, position and depth, pairwise contrasts showed that Conv 267N differed significantly only from Conv 0N and GM 0N for a limited number of sub-effects. Neither Conv 133N nor GM 133N differed significantly from Conv 267N in any pairwise contrast, although RLD for GM 133N was greater than Conv 267N by 22% in the upper 15 cm of soil (data not shown).

Soil water potential. Soil water potential for GM 133N and Conv 200N at 15 cm showed two distinct phases. From 17 April until 20 May (about 0–5 WAE), soil water potential under GM 133N remained significantly higher than Conv 200N by an average of 2.6 ± 0.2 kPa (Fig. 3A). Average soil water potentials at 15 cm during this period were -16.5 ± 0.4 kPa for GM 133N and -19.1 ± 0.5 kPa for Conv 200N. Greatest differences occurred during the 12-day period from 19 April to 1 May when soil water potential under GM 133N was 3.9 ± 0.1 kPa higher than under Conv 200N. From 21 May until final harvest on 19 June (about 5–9 WAE) this trend reversed, with soil water potential under Conv 200N (-13.7 ± 0.2 kPa) becoming significantly higher than in GM 133N (-14.9 ± 0.1 kPa) by an average of 1.2 ± 0.2 kPa. Overall, average daily soil water potential for both treatments increased logarithmically over the season, probably reflecting greater water potential near the surface after canopy closure and shading (Fig. 3A).

Soil water potential at 60 cm also underwent two distinct phases but with an intermediate 'transition' period during which water potential in both GM 133N and Conv 200N was relatively equal (Fig. 3B). From 17 April to 5 May (about 0–3 WAE) soil water potential at 60 cm remained lower in GM 133N (-15.1 ± 0.5 kPa) compared to Conv 200N (-13.9 ± 0.3 kPa) by an average of 1.2 ± 0.3 kPa. Soil water potential for the two treatments at 60 cm was not significantly different from 6 May to 25 May (about 3–6 WAE), but from 26 May to final harvest (about 6–9 WAE) tensiometer readings showed higher soil water potential for GM 133N (-11.8 ± 0.4 kPa) compared to Conv 200N (-13.8 ± 0.5 kPa) by an average of 2.0 ± 0.2 kPa. Tensiometer readings from 90 cm showed lower soil water potential throughout the season for GM 133N (-10.2 ± 0.4 kPa) compared to Conv 200N (-8.8 ± 0.3 kPa) by an average of 1.4 ± 0.3 kPa (data not shown).

2004 Experiment

RLD and relative root length distribution. Because sample dates and timing of N fertilization differed, results from the 2004 experiment cannot be compared statistically to the 2003 experiment. However, across all sample dates (4, 6 and 9 WAE) and treatments (GM 133N, Conv 133N and Conv 267N) within the 2004 experiment, the range of RLD in the upper 0–60 cm soil layer remained between 0.13 and 1.64 $cm\,cm^{-3}$, similar to the range found in the 2003 experiment. Use of GM again increased corn RLD by 54%. Unlike results from 2003, this increase occurred throughout the upper 60 cm of soil (Table 3). Also unlike the 2003 experiment, pairwise contrasts showed GM 133N to have significantly higher

Table 2. RLD (cm cm^{-3}) by interactions between position and date, position and depth, position and N rate, depth and date, and depth and N rate in the 2003 experiment.

	Position				Depth		
Date	**IR0**	**IR0.5**	**BR**	**Date**	**15 cm**	**30 cm**	**60 cm**
3WAE	0.37Ba	0.36Ba	0.22Bb	3WAE	0.69Ba	0.54Bb	0.24Cc
5WAE	1.07Aa	0.91Aa	0.47Ab	5WAE	2.43Aa	1.33Ab	0.44Bc
8WAE	1.25Aa	1.00Aa	0.49Ab	8WAE	2.83Aa	1.50Ab	0.55Ac
Depth				**N rate**			
15 cm	2.63Aa	2.08Aa	1.25Ab	0N	1.34Ba	0.87Bb	0.33Bc
30 cm	1.51Ba	1.45Ba	0.41Bb	133N	2.63Aa	1.38Ab	0.49Ac
60 cm	0.51Ca	0.45Ca	0.27Bb				
N rate							
0N	1.11Ba	0.99Ba	0.59Ab				
133N	2.07Aa	1.84Aa	0.89Ab				

N, kg chemical N ha^{-1}. Means within rows having same lower case letters and means within columns having same capitalized letter do not differ at the $P \leq 0.05$ level according to Duncan's multiple range test.

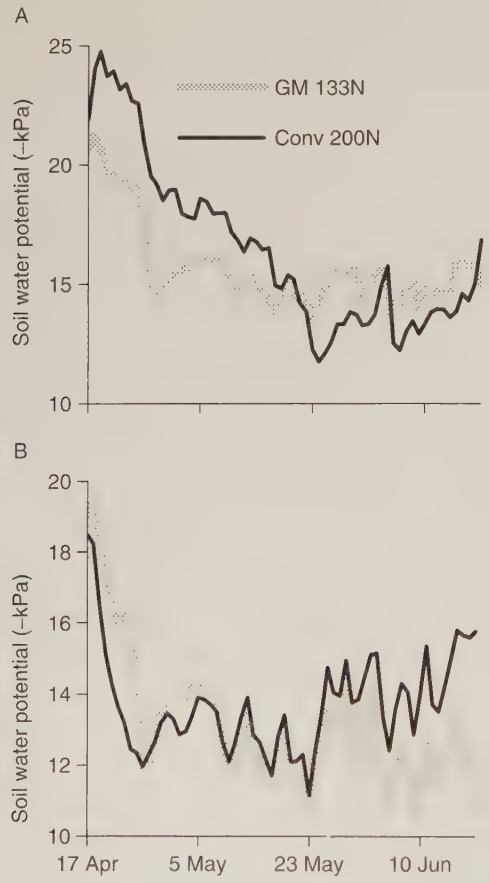

Figure 3. Soil water potential at 15 cm (A) and 60 cm (B) during sweet corn growth in the 2003 experiment. Data are shown for sweet corn following GM and fertilized with 133 kg chemical N ha^{-1} (GM 133N) and sweet corn fertilized with 200 kg chemical N ha^{-1} only (Conv 200N).

RLD than Conv 267N (by 44%) throughout the upper 60 cm of soil (Table 3).

Although full ANOVA indicated significant interactions for position × date and position × depth (Table 3), sub-effects were non-significant (Table 4). RLD appeared relatively unaffected by date, probably due to later initial sampling (4 WAE) than in the 2003 experiment. RLD increased when moving from BR to either IR position during any sample date and increased from lower to higher depth without apparent interaction with position (Table 4).

Corn RLD distribution was qualitatively similar to that found in the 2003 experiment. Roughly 75% of sampled RLD existed in the IR position, and about 95% of sampled RLD existing in the upper 30 cm. However, at final sampling (9 WAE, coinciding with maturity), corn in sub-plots with broadcast application of 133 kg N ha^{-1} showed more even distribution of roots than corn with banded N when comparing RLD for BR and IR positions (Fig. 4). BR RLD in banded treatments amounted to only 26% of total sampled RLD, while in broadcast treatments this proportion increased to 41%. However, pairwise contrasts of corn RLD between broadcast and banded treatments showed no significant differences, nor did GM application, position and depth have interactive effect with the method of N application on corn root RLD at this date. As in the 2003 experiment, representation of data as relative root lengths did not qualitatively alter statistical results, indicating that absolute trends in RLD did not mask changes in relative root distributions.

Discussion

Despite variability inherent in root core work, we resolved definite patterns of corn root distribution within the study environment. These patterns help explain corn growth and yield performance as found by Cherr[5] and Avila (2004, unpublished). Including weeds and stover from corn crops, use of a productive GM system contributed about 20 Mg residue ha^{-1} yr^{-1}, roughly 10–12 Mg ha^{-1} yr^{-1} more than the conventional approach. About half of this residue was

Table 3. Significance of treatment, date, position, depth and sub-effects when constituting linear model for sampled RLD in the 2004 experiment.

Model term	Probability (P)
Main effects	
Date	0.0002
Pos	<0.0001
Depth	<0.0001
Trt	<0.0001
GM 133N	1.09a
Conv 133N	0.71b
Conv 267N	0.76b
Two-way interactions	
Date × Pos	0.0189[1]
Date × Depth	NS
Pos × Depth	<0.0001[1]
Date × Trt	NS
Pos × Trt	NS
Depth × Trt	NS
Three-way interactions	
Date × Pos × Depth	NS
Date × Pos × Trt	NS
Date × Depth × Trt	NS
Pos × Depth × Trt	NS
Four-way interaction	
Date × Pos × Depth × Trt	NS

Trt, treatment; Pos, position; N, kg chemical N ha^{-1}; NS, not significant at the $P \leqslant 0.05$ level.
[1] See Table 4.

Table 4. Effects of interactions between position and date or depth on RLD (cm cm^{-3}) in the 2004 experiment.

	Position	
Date	**IR**	**BR**
4WAE	0.85Aa	0.42Ab
6WAE	1.50Aa	0.43Ab
9WAE	1.46Aa	0.48Ab
Depth		
0–15 cm	3.15Aa	1.16Ab
15–30 cm	1.36Ba	0.44Bb
30–60 cm	0.29Ca	0.09Cb

Means having same letters do not differ at the $P \leqslant 0.05$ level according to pairwise contrast.

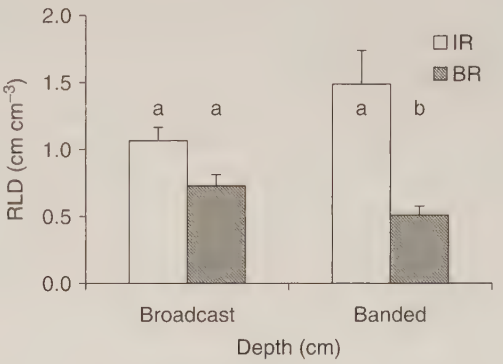

Figure 4. Effect of chemical N application method on sampled sweet corn RLD by position in the 2004 experiment. Error bars reflect standard errors; lower case letters reflect ANOVA differences within application method, $P \leqslant 0.05$.

highly recalcitrant stem material from SH. After 2–3 years in a reduced-tillage system on sandy soil, these GM additions increased sweet corn RLD by 44–54%, although in the 2003 experiment doing so only in the upper 15 cm of soil.

In the 2003 experiment, GM amendment benefited corn RLD throughout the upper 60 cm of soil and at late-season (1 week before harvest) only without chemical N (GM 0N). Increased root proliferation near the soil surface may have occurred if GM residue slowed the movement of chemical N fertilizer through immobilization and subsequent re-mineralization. In the 2004 experiment, differences in scheduling of chemical N application to corn and accumulation of organic matter from an additional year of GM growth may have distributed the significantly positive RLD response to GM more evenly throughout the upper 60 cm. However, increased sample variability, fewer samples, and later sample dates may have also masked finer differences between depths.

Although corn with 267 kg N ha^{-1} received roughly 40 kg N ha^{-1} more than corn in GM 133N treatments (when considering both GM residues present at the time of corn planting and chemical N applied to corn), corn with GM 133N maintained RLD up to 44% greater than Conv 267N. Detailed growth analysis for corn from the 2003 experiment revealed that GM 133N performed similarly to Conv 267N throughout the growing season in terms of tissue dry weights and leaf indicators[5]. Tensiometer data from the 2003 experiment reveals that surface residue may also have created an environment of greater water availability at 15 cm below the soil surface, especially early in the season before canopy closure (Fig. 3A). Coupled with possible net N release from decomposition, root proliferation near the soil surface may have benefited plants during early-season. Only during the final week before maturity did total plant N mass and ear dry weight for Conv 267N become significantly greater than that of GM 133N. By late-season, the moisture level at 15 cm depth in GM 133N treatments dropped below that of conventionally fertilized corn of similar biomass. Root proliferation above 15 cm may therefore have exposed plants to water stress during ear fill, although it should be noted that water potential at 15 cm in both treatments rose over time (probably due to shading from canopy closure). Higher late-season water potential at 60 cm in GM 133N plots (compared to conventional) also suggests that corn in this treatment took up less water at lower depths during late-season

compared to conventionally fertilized corn of similar biomass (Fig. 3B).

Growth analysis from the 2003 experiment also demonstrated significant late-season uptake of N by sweet corn[5]. Corn in Conv 267N treatments, receiving roughly 40 kg total N ha^{-1} more than GM 133N (including both residue and chemical N sources), may have benefited from late-season uptake of this 'additional' N. Root proliferation near GM residue on the soil surface may have allowed corn in GM 133N treatments to remain competitive if there was an increased water and/or higher N release beneath residue despite lower chemical N rate, especially during early and mid season. Similar root distribution effects were reported by Thorup-Kristensen and van der Boogard[18] for carrot amended with large amounts of surface-applied GM. These results complement and contrast findings under conventional tillage, where GM use also appears to increase overall RLD but at lower soil depths[16,17], while chemical approaches to N fertilization may encourage root proliferation near the soil surface[15].

In the 2003 experiment, GM amendment benefited corn RLD throughout the upper 60 cm of soil and at late-season (1 week before harvest) only in the absence of chemical N fertilizer. More uniform RLD response to GM from unfertilized corn (compared to fertilized corn) may have been related to more uniform availability of soil N underneath recalcitrant SH residue when chemical N was not applied. Attempts to quantify soil solution N levels using suction lysimeters were unsuccessful. More uniform increase of RLD with GM use might be desirable if it increased overall N and/or water uptake. However, corn in GM 0N treatments achieved only 46 and 3% of dry weight and marketable ear yields, respectively, produced by Conv 267N during the 2003 season. Therefore, such an approach to sweet corn production is not practical in our environment.

Providing GM with N content closer to that applied with chemical fertilizer must remain a priority. However, it is unclear if shallow-root proliferation beneath GM residue resulted in a net disadvantage for sweet corn growth. Soil incorporation of GM residue to help encourage deeper root growth under these circumstances might be favorable if subsequent nutrient loss from decomposition did not negate the benefits. However, in warm humid areas with coarse-textured soil, reduced tillage is often desired to slow organic matter decomposition and nutrient loss and improve soil water retention[19–22]. In such reduced-tillage systems, improved use of GM may necessitate different irrigation managements, including drip lines buried below surface residue and/or use of small, frequent irrigations during the late-season. Use of individual GM species or GM mixtures with more substantial below ground production (e.g., tuber crops) may also create a better rooting environment at deeper depths, and may also be important for increasing N retention[5].

Generally, maximum sweet corn RLD was achieved by 4–5 WAE in all treatments in both experiments. Significantly, more corn RLD existed near the soil surface and at IR positions (relative to BR positions), and RLD increase over time appeared slower in the BR position (both absolutely and as proportion of pre-existing roots). In the 2004 experiment, however, broadcast application of N resulted in more even distribution of corn roots between IR and BR positions near maturity. Coelho and Or[23] showed that for corn a relatively minor fraction of total RLD located BRs can make disproportionately large contributions to root water uptake when water becomes more available there than closer to the plant. However, increases in the effective N contributions from GM probably must accompany improvements in corn root distribution, and root uptake potential must match the timing and location of N and water availability.

Conclusions

Use of GM may alter root distribution patterns of subsequent crops, possibly with effects on production. In a reduced-tillage system on sandy soil with band applied chemical N, GM increased sweet corn RLD, but one of the two experiments did so only in the upper 15 cm of soil. Despite receiving up to 40 kg total N ha^{-1} less (including organic and inorganic sources), corn in rotation with GM plus 133 kg inorganic N ha^{-1} maintained RLD equal to or greater than corn with 267 kg inorganic N ha^{-1} in both experiments. Increased water and/or N availability in the upper soil depth during early-season may have given corn following GM an advantage at this time, but by late-season lack of N and/or water in this layer may have reduced ear-fill.

Most sweet corn root length appeared to exist within 30 cm of the soil surface and to occur near the plant. Water and nutrients well below this depth and/or in between row areas may become relatively unavailable for these plants. Broadcast application of chemical N may encourage more even distribution of root growth throughout the plot, but it remains unclear if this root growth occurs in the proper amount and timing to take up N in the between row area.

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Do the new organic producers differ from the 'old guard'? Empirical results from Norwegian dairy farming

Ola Flaten[1,*], Gudbrand Lien[1], Martha Ebbesvik[2], Matthias Koesling[2] and Paul S. Valle[3]

[1]Norwegian Agricultural Economics Research Institute (NILF), Box 8024 Dep., NO-0030 Oslo, Norway.
[2]Norwegian Centre for Ecological Agriculture, NO-6630, Tingvoll, Norway.
[3]Department of Production Animal Clinical Sciences, Norwegian School of Veterinary Science, Box 8146 Dep., NO-0033, Oslo, Norway.
*Corresponding author: ola.flaten@nilf.no

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Abstract

Conventional farmers converting to organics have contributed to most of the rapid expansion of organic farming in recent years. The new organic farmers may differ from their more established colleagues, which may have implications for the development of the organic farming sector and its distinctiveness vis-à-vis conventional production and marketing practices. The aim of this study was to explore Norwegian organic dairy farmers' personal and farm production characteristics, farming goals, conversion motives, and attitudes to organic farming, grouped by year of conversion (three groups). A postal survey was undertaken among organic dairy farmers ($n = 161$). The results show that the newcomers (converted in 2000 or later) were less educated than the early entrants (the so-called 'old guard') who converted in 1995 or earlier. The frequency of activities like vegetable growing and poultry farming among the old guard was high. The late-entry organic herds were fed with more concentrates and had a higher milk production intensity, showed a higher incidence of veterinary treatments and less frequent use of alternative medicine than the herds of the two earlier converting groups. For all groups of farmers, the highest ranked farming goals were sustainable and environment-friendly farming and the production of high-quality food. Late entrants more often mentioned goals related to profit and leisure time. On average, the most frequently mentioned motives for conversion were food quality and professional challenges. The old guard was more strongly motivated by food quality and soil fertility/pollution issues than the others, whereas financial reasons (organic payments included) were relatively more important among the newcomers. All groups held very favorable views about the environmental qualities of organic farming methods, albeit with different strengths of beliefs. Even though trends towards more pragmatic and business-oriented farming were found, the majority of the newcomers were fairly committed.

Key words: organic farming, milk production, year of conversion, farming goals, motives for conversion, attitudes, animal health, feeding, conventionalization

Introduction

Organic farmers have been critical of mainstream conventional agriculture, its industrialization and the productivity paradigm. The organic pioneers' idea was to develop the farm as a system that makes use of its own resources as far as possible and only draws on external resources when necessary and appropriate[1]. Today, organic farming has a wide range of sustainability and environmental objectives. The organic movement, originally consisting of a small number of 'particularly committed' farmers and consumers, established alternative, grass roots-oriented production and distribution systems.

Organic farming has become more popular, as consumer demand has increased. Currently, more than 26 million ha are farmed organically worldwide[2]. Of this figure, 11.3 million ha are in Australia, mostly extensive grazing land. In USA, 0.93 million ha are managed organically, representing 0.22% of the farmland. The percentage of organically farmed land is highest in Europe (more than 2% of the farmland). In Europe, almost 6.3 million ha are managed organically by almost 170,000 farmers. Since the early 1990s, the growth in Europe has been associated with public support for organic farming[3,4]. After years of rapid organic food sales growth, the market is now maturing in many European countries.

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Along with organic farming's popularity, some researchers have warned that the organic movement may be in danger of losing its identity, with agribusiness involvement and abandoning of the more sustainable agronomic and marketing practices originally associated with organic agriculture[5–7]. For example in California, allowance of 'natural' inputs, like sulfur dust to control fungus, has facilitated organic production of specific crops like grapes[7]. This argument has been canonized as the 'conventionalization thesis'. Others describe organic agriculture as a useful and complex example of the way in which nature features in contemporary food production and consumption[8,9]. Besides, it is apparently impossible to disentangle the organic food production from the organic social movement[3,10].

Some studies have examined characteristics, motives and attitudes of organic farmers, and how the conversion year impacts the variables. An early study classified Norwegian organic farmers into two main groups[11]. The first group, the pioneers, of cosmopolitan organic farmers had a strong ideological foundation based on ideas from anthroposophy or eco-philosophy. The second group was of locally oriented farmers who wanted to farm in an environment-friendly way, but their ideological orientation was less pronounced.

A literature review[12] concluded that motives for conversion appeared to have changed from the earlier philosophical ideals and husbandry and technical reasons towards an increasing focus on environmental and economic concerns, and the perception of organic farming as a professional challenge. The importance of subsidies for farmers' decisions to convert has not been studied in detail[13]. There has been little direct research about the goals of organic farmers[12]. Several studies of organic farmers have looked at personal and social characteristics, such as farm size, farming background and education, and the farmers' attitudes (reviewed by Padel[12]), but little is known about, for example, gender issues. Moreover, few studies have carried out a rigorous comparison of farm and personal characteristics of the early entrants (the 'old guard') versus the new (late-entry) organic producers[12].

This exploratory study aims to fill parts of these gaps by providing empirical information about Norwegian organic farmers' personal and farm characteristics, farming goals, motives for conversion, and attitudes to organic farming, grouped by year of conversion. The study is restricted to dairy farming because it is the dominant form of organic livestock production in Norway. In addition, comprehensive farm level data regarding production records and animal health management are available.

Organic Farming in Norway

Organic farming in Norway started in the early 1930s, but until the 1970s there were just a few organic farms in the country. Most of the pioneers followed Rudolf Steiner's biodynamic farming principles. Nowadays fewer than 30 Norwegian farmers follow these principles.

An organic farmers' organization was first established in 1971. In 1986, the certification and inspection organization *Debio* was founded. Debio certifies all organic production methods. Debio also implements the official national standards for organic farming. The Norwegian legislation is subject to the EU regulations for organic plant production from 1991 (EC Regulation No. 2092/91) and supplemented by common standards for organic animal husbandry from 1999 (EC Regulation No. 1804/1999).

Since the 1990s, public initiatives encouraged farmers to convert to organic production. Conversion grants and support schemes for organic farmland were introduced in 1990. A scheme enabling farmers to apply for free organic milk quotas was launched in 1995, and area payments, particularly for organic grain, gradually increased. Organic livestock payments were established in 2001. The food industry introduced organic premiums on several products, milk and beef included, in 1996.

The number of organic farms increased from 423 in 1991 to 2484 in 2004[14]. In the same period, the area of organically certified farmland and land in conversion increased from 2443 ha to 41,036 ha. In 2004, the organic area and land in conversion amounted to 4.0% of the total farmland. Organic milk production increased from 3.6 million liters in 1997 to 24.3 million liters in 2004. A total of 1.6% of all milk produced in 2004 was organic[15].

One of the Ministry of Agriculture's prevailing aims is to achieve 10% organically managed area by 2009[16]. Organic farming methods are said to contribute to food safety, greater product diversity, environmental benefits, sustainability, enhanced farm incomes and reduced food surpluses. The land area target must however coincide with adequate development of the organic markets. The share of organic milk reaching consumers as organically labeled products was only 25% in 2004[15], i.e., 75% of organically produced milk was going into conventional dairy products. The Norwegian dairy cooperative TINE, the main purchaser of milk from farmers, guarantees organic farmers in the main organic dairy areas a price premium of NOK (Norwegian kroner) 0.60 per liter of milk ($1 ≈ NOK 6.40) until the end of 2005. Supply chain and marketing issues have to be seriously addressed to mitigate the organic milk supply–demand imbalance and its resulting downward pressure on farm-gate prices in the years to come. One recent effort by TINE, expected to double the sale of organic milk products, is to make kefir-fermented milk only from organic milk.

Generally, climatic and topographical conditions contribute to high costs of agricultural production in Norway and farm support is consequently high. Agricultural policies have encouraged agriculture's multifunctionality and contribution of public goods to society, e.g., rural viability, landscape preservation, food security and cultural heritage[17]. Farm support programs have accordingly favored small family farms. Problems related to food safety and environmental issues have been few. The potential market for organic food will, therefore, have better conditions in other high-income countries with a higher degree of

industrialized agriculture and/or problems with food-borne diseases than in Norway[18]. Another challenge for the development of organic farming in Norway is the small population of 4.6 million, which is spread over a wide area.

Materials and Methods

Data and sample

Data from organic dairy farmers examined in this paper were collected as part of a larger questionnaire survey among Norwegian farmers[19,20]. Data (2002) from the Norwegian Agricultural Authority (SLF), the Norwegian Dairy Herd Recording System and the Norwegian Cattle Health Services were merged with the questionnaire data.

The questionnaire was first sent out in January 2003 to all 245 registered producers of organic milk. Some 161 (65.7%) farmers responded, of which 92% participated in the Norwegian Dairy Herd Recording System and the Cattle Health Services.

Questionnaire design

The questionnaire presented farmers with questions related to: (1) farm and farmer characteristics; (2) farmers' goals and motives for their farming system; (3) a series of statements designed to test their attitudes with regard to characteristics of organic farming compared to conventional farming; (4) livestock disease management strategies, including their use of alternative veterinary medicine (homeopathy, acupuncture, herbal medicines, etc.); and (5) farmers' risk perceptions and management responses.

Farmers were asked to report the year in which the farm's first field(s) was certified as organic farmland. This year was presupposed to be the year of conversion to organic farming.

From a list of 14 (10) farming goals (motives for conversion), the respondents were asked to select up to five goals (three motives) as most important for them. Goals and motives were treated as categorical binary data: 'important' if the goal (motive) was rated among the five (three) most important, and 'less important' otherwise.

Respondents' attitudes were examined by means of a series of statements. Farmers were asked to score each attitudinal question on a seven-point Likert-type scale. The Likert-type scales were considered as metric variables.

Statistical analyses

The respondents were categorized into three groups, representing the year of conversion to organic farming: (1) those who had farmed organically since 1995 or earlier (*early converters*, i.e., the 'old guard'); (2) those who were certified in the years 1996 to 1999 (*mid converters*); and (3) those who started farming organically in 2000 or later (*late converters*, i.e., the new producers). The categorization was based on several concerns: phases in the development of the organic farming sector in Norway; avoidance of insensitiveness of statistical tests due to small sample sizes; and finally, subjective judgments.

Mean values obtained in different groups for metric variables were compared by *t*-tests. Chi-square statistics were generated for comparisons of frequencies of categorical data.

Results and Discussion

Key respondent characteristics

Personal characteristics of the three groups are shown in Table 1. The mean scores in the groups and the total mean are reported along with the results of the significance tests.

The average organic dairy farmer was 47 years old and had 23 years of farm experience. Late entrants were significantly younger and had less farming experience than the two earlier groups.

Female farm owners comprised just 14% of the farms. Storstad and Bjørkhaug[18] sampled from all organic farmers in Norway and found a higher share of female organic farmers (20%). Replies to the question on farm management responsibility also indicated few females. The early entrants had a higher portion of farms with divided responsibility between persons, suggesting that females on these farms were more involved in the farm decision-making. At the same time, females on early converting farms were less involved in off-farm work than in the later groups. More than 40% of the respondents had some college or university education, quite similar to the 34% observed among all Norwegian organic farmers[18]. Early entrants had a significantly higher educational level than the late entrants.

Farm production

Farm production practices for the three groups are shown in Table 2. The mean scores in the groups and total mean are reported along with the results of the significance tests.

A greater number of the old guard farmers, compared to the mid and late entrants, cultivated 'other crops' and kept poultry, however, usually on a very small scale. They also tended to more mixed livestock farming than the later groups. These findings indicate that a substantial part of the old guard follow the organic ideals and traditions of mixed farming and farm household self-sufficiency. These strategies are evidently less common among later entrants and may influence the sustainability of the organic farming practices.

Supply of concentrates per cow was quite similar between the two earliest groups, while the new producers' cows were fed with more concentrate. The higher concentrate feeding intensity was associated with a higher milk yield per cow. Lower milk production per cow in old organic herds was also found in a Danish study[21]. The late entrants' average milk yield of 5398 kg per cow was low compared to the overall average of 6190 kg in Norwegian dairy herds[22]. Further, only 11% of the organic herds

Table 1. Mean characteristics of farmers grouped by year of conversion.

Characteristic	Early converters (1)	Mid converters (2)	Late converters (3)	All	Significant difference[1]
Number of respondents	45	68	48	161	
Age of farmer[2]	50.5	48.4	42.8	47.2	**1–3, 2–3**
Farming experience (years)	23.3	24.9	18.7	22.6	1–3, **2–3**
Years since conversion (2003 reference)	12.6	5.4	1.8	6.3	**1–2, 1–3, 2–3**
Farmer's age at conversion[2]	39.1	43.0	41.0	41.4	1–2
Marital status (% married farmers)	97.6	89.6	95.8	93.6	
Family farm (% of farms)	88.6	93.9	93.8	92.4	
Gender (% female owners, family farms)	13.2	11.3	17.0	13.8	
Farm management responsibility (%)[3]	5/49/46	7/65/28	10/63/27	8/60/32	**1–2, 1–3**
Off-farm work (% of farms)[4]	62.2	76.5	70.8	70.8	
Off-farm work (% of farm wives)	55.3	74.6	71.1	67.9	1–2
University/College education (% of farmers)	53.7	38.2	31.3	40.1	1–3
Agricultural education (% of farmers)	82.5	77.9	68.1	76.1	
Farm income (% of farmers)[5]	46.3	43.3	52.1	46.8	
Household income (% of farmers)[5]	43.9	50.8	55.3	50.3	
Location (% of farmers)[6]	46.7	39.7	37.5	41.0	

'Early converters' = conversion in 1995 or earlier; 'Mid converters' = 1996–1999; 'Late converters' = 2000 or later.
[1] Significant differences are in italics ($P < 0.10$), normal ($P < 0.05$) or bold ($P < 0.01$), based on t-tests for metric variables and chi-square tests for categorical variables.
[2] Data from SLF (the Norwegian Agricultural Authority), age only of family farm owners.
[3] Principal person(s) in charge of farm management: woman/man/split between two or more persons.
[4] Percentage of farms where the farmer and/or the spouse had some off-farm work.
[5] Percentage of farms with farm income (household income) higher than NOK 200,000 (NOK 350,000).
[6] Percentage of farms located close to urban areas (with no regional policy priority).

exceeded 6500 kg per cow in milk yield. Of these, 56% were in the late-entry group. On the other side, 15% of the herds achieved less than 4000 kg milk per cow, in part due to the use of indigenous cattle breeds. The greater part of the farms thus had a low to moderate milk production intensity. The findings do not suggest widespread 'intensification' of milk production.

Late entrants replaced more heifers than early entrants. Culling rates were more similar among the groups. A German study also found less intensive replacement and culling policies in older organic herds[23].

The late organic herds showed the highest level of registered disease treatments per cow, mainly related to veterinary visits and medical treatments. Similar trends were found for mastitis treatment in Denmark[21]. A vital question is, however, whether the registered disease treatments actually mirror the true number of diseases in the herd. The farmer's threshold for veterinary treatment of diseases, *inter alia* influenced by the degree of self-initiated non-medical disease handling, affects the resulting treatment rate. Further, alternative treatments are seldom reported to the Cattle Health Services, and the earliest groups had a significantly higher user frequency of alternative medicine. The use of alternative medicine and treatment methods is recommended by organic farming standards, but almost 40% of the farmers never used it.

To summarize, the findings suggest differences in agronomic and husbandry practices between the groups. Since the late entrants had converted recently, a question of how much the long-term effects of organic farm management practices really had shown up in these herds may be raised.

Farmers' goals

Table 3 shows the percentage of farmers in the groups rating various farm goals as important, and whether the ratings by the groups differed significantly.

Most farmers reported multiple goals. The highest ranked goal in general was 'sustainable and environment-friendly farming', rated as important by more than 80% of the respondents. The goal 'producing high-quality food' followed close behind. The least important goals were 'higher private consumption' and 'increase equity'.

The goals of converters to organic farming have changed over time. Nearly 70% of the late entrants had 'sustainable and environment-friendly farming' as an important goal, while the rate was close to 90% in the old guard. A higher frequency of the late entrants found 'have sufficient leisure time' important. Profit maximization ranked very low in the early and mid group, while it was mentioned more frequently among the late entrants. Relatively low ranking of profit maximization has also been found in previous studies of conventional farmers' goals[24,25]. Even though goals of profit and leisure time had become more important, environmental and food quality goals were the most frequently stated goals among the new organic producers, as well.

Table 2. Mean values of farm production practices grouped by year of conversion.

Characteristic	Early converters (1)	Mid converters (2)	Late converters (3)	All	Significant difference[1]
Labor					
Farm labor units (man-years)	2.19	2.06	2.19	2.13	
Land management					
Farmland (ha)[2]	29.2	28.9	33.0	30.2	
Grassland (ha)[2]	24.5	25.3	28.2	25.9	
Grain (ha)[2]	4.0	3.4	4.3	3.8	
Grain (% of farms)[2]	53.3	35.3	47.9	44.1	*1–2*
Other crops (% of farms)[2,3]	55.6	22.1	22.9	31.7	**1–2**, **1–3**
Stocking rate [LU (ha UAA^{-1})][2,4]	1.24	1.10	1.18	1.16	
Livestock management					
Number of dairy cows[2]	16.6	16.4	17.4	16.7	
Number of young cattle[2]	23.6	22.9	28.2	24.6	*2–3*
Milk yield per cow (kg year^{-1})[5]	4830	5073	5398	5110	1–3
Concentrates (FUm cow^{-1})[5,6]	819	836	1006	885	1–3, 2–3
Heifer replacement (% of cows)[5]	33.9	36.3	41.0	37.1	*1–3*
Culling rate (% of cows)[5]	35.6	34.0	38.1	35.7	
Other mammals (% of farms)[2,7]	51.1	36.8	33.3	39.8	*1–3*
Poultry (% of farms)[2,8]	40.0	13.2	12.5	20.5	**1–2**, **1–3**
Animal health					
No. of disease treatments/100 cows[5]	32.7	39.4	53.0	41.9	*1–3*
Use of alternative medicine (% of farmers)	77.5	66.7	43.5	62.5	**1–3**, 2–3

[1] Significant differences are in italics ($P < 0.10$), normal ($P < 0.05$) or bold ($P < 0.01$), based on *t*-tests for metric variables and chi-square tests for categorical variables.
[2] Data from SLF.
[3] Percentage of farmers having 0.2 ha or more of potatoes, vegetables, fruit or berries.
[4] Livestock units (LU) per ha utilizable agricultural area (UAA). Figures are based on number of livestock and hectares from the Norwegian Agricultural Authority, and LU numbers in Debio[14].
[5] Data from the Norwegian Herd Recording System and the Norwegian Cattle Health Services.
[6] One feed unit milk (FUm) is defined as 6900 kJ of net energy lactation.
[7] Farms having at least two other animals (suckler cows, sheep, goats, pigs and horses).
[8] Farms having hens, chicken, turkeys, ducks or geese.

Table 3. Farmers' goals grouped by year of conversion.

Goal	Early converters (1)	Mid converters (2)	Late converters (3)	All	Significant difference[1]
Sustainable and environment-friendly farming	88.9	83.8	68.8	80.8	1–3, *2–3*
Producing high-quality food	80.0	77.9	75.0	77.6	
Reliable and stable income	51.1	60.3	58.3	57.1	
Time for family, living quality for children	62.2	50.0	54.2	54.7	
Independency, self-employment	46.7	47.1	37.5	44.1	
Work with animals/crops	40.0	30.9	39.6	36.9	
Improve the farm for the next generation	28.9	44.1	27.1	34.8	*2–3*
Have sufficient leisure time	17.8	17.7	37.5	23.6	1–3, 2–3
Reduce debt, become free of debt	13.3	23.5	27.1	21.7	
Continue to be a farmer	13.3	19.1	25.0	19.3	
Maximize profit	6.7	10.3	22.9	13.0	1–3, *2–3*
Social contacts	11.1	8.8	4.2	8.1	
Increase equity	6.7	0.0	2.1	2.5	*1–2*
Higher private consumption	0.0	0.0	0.0	0.0	

Percentage of farmers ranking the goal as one of the five most important goals. Ranked in order of declining importance for the group all farmers.
[1] Significant differences are in italics ($P < 0.10$), normal ($P < 0.05$) or bold ($P < 0.01$), based on the chi-square tests.

Table 4. Farmers' motives for conversion grouped by year of conversion.

Motive	Early converters (1)	Mid converters (2)	Late converters (3)	All	Significant difference[1]
Food quality	62.2	45.6	41.7	49.1	*1–2*, 1–3
Professional challenges	33.3	47.1	45.8	42.9	
Soil fertility, pollution problems	51.1	35.3	27.1	37.3	*1–2*, 1–3
Ideology, philosophy	40.0	35.3	25.0	33.5	
Health risks (pesticides, etc.)	24.4	36.8	33.3	32.3	
Animal welfare	22.2	32.4	33.3	29.8	
Profitability	11.1	22.1	37.5	23.6	**1–3**, *2–3*
Organic farming payments	6.7	10.3	35.4	16.8	**1–3, 2–3**
Natural conditions (soil, climate, etc.)	8.9	7.4	10.4	8.7	
Income stability	2.2	4.4	2.1	3.1	

Percentage of farmers ranking the motive as one of the three most important motives. Ranked in order of declining importance for the group all farmers.
[1] Significant differences are in italics ($P < 0.10$), normal ($P < 0.05$) or bold ($P < 0.01$), based on the chi-square tests.

Motives for conversion

Table 4 shows the percentage of farmers in the groups rating various motives for conversion to organic farming as important, and whether the ratings by the groups differed significantly.

On average, the most important motives for conversion were 'food quality' and 'professional challenges'. The least important motives were 'income stability' and 'natural conditions'. Among the old guard, 'food quality', 'soil fertility, pollution problems' and 'ideology, philosophy' appeared most frequently, whereas 'professional challenges' and 'food quality' were ranked highest in the later groups.

A significantly higher frequency of the late entrants than respondents in the earlier groups mentioned 'profitability' and the 'organic farming payments' as important motives. However, the traditional environmental, food quality and philosophical concerns were more widely present as motives for conversion. 'Food quality' and 'soil fertility, pollution problems' motives appeared more frequently among the old guard. Our findings are quite similar to previous studies reviewed by Padel[12], and a recent study of Swedish livestock farmers[26].

Norwegian organic farmers have been viewed as consistently idealistic[27]. The understanding of organic farming has partly been different from, for example, Sweden, where tougher economic conditions have forced farmers to become more pragmatic in order to survive. This study indicates that the number of profit-oriented pragmatists is also on the rise in Norway.

Farmers' attitudes

Farmers' perceptions of the attitudinal questions are reported in Table 5.

In general, all groups of organic farmers held very favorable views about the qualities of organic farming methods. For most statements, and five of them significantly, the early converters expressed stronger beliefs in the organic farming methods than later converters. The largest divergence in attitudes between the early and mid group was: 'conventional livestock farming improves animal health', and between the early and late group: 'use of pesticides decreases food quality'.

The most favorable statements (highest pro-organic overall mean score) were: 'larger biodiversity in organic farming' and 'fertilizer use is necessary to avoid soil exhaustion'.

The statements being least supportive of organic farming were: 'without herbicides weed problems increase' and 'organic livestock farming increases the risk of underfeeding and malnutrition'. About 26% of the farmers agreed (i.e., scored 5, 6 or 7 on the Likert-type scale) that weed problems increase without herbicides, while 15% agreed with the increased risk of malnutrition in organic farming. The results indicate that strategies for controlling weeds need to be considered thoroughly for farmland under organic management. Also, organic livestock production has occasionally been criticized because animals have been malnourished[27,28].

The attitudinal responses contrast somewhat with earlier results in this study. Earlier variables were quite different among the three groups, particularly between the old guard and the new producers. In this case, the three groups held quite similar views, albeit with different strength of beliefs. The questions were restricted to environmental values. Questions related to holistic aspects of organic farming, also involving social, cultural and human values, may have resulted in larger dissimilarities between the groups.

Implications and Conclusions

The area of land and number of farms under organic management in Norway have increased rapidly, as in many other countries worldwide. Most of the new players contributing to the growth in organic production must necessarily be conventional farmers converting to organics. In situations where organic farming has become more

Table 5. Farmers' attitudes grouped by year of conversion.

Statement	Early converters (1)	Mid converters (2)	Late converters (3)	All	Significant difference[1]
'More biodiversity in organic farming'	6.73	6.41	6.38	6.49	*1–3*
'Fertilizer use is necessary to avoid soil exhaustion'	1.41	1.63	1.57	1.55	
'Fertilizers have to be applied to supply nutrients just in time'	1.51	1.62	1.81	1.64	
'Conventional livestock farming improves animal health'	1.38	1.97	2.07	1.83	**1–2**, 1–3
'Conventional farming is more sustainable than organic'	1.82	2.00	1.79	1.89	
'Use of pesticides decreases food quality'	6.44	6.26	5.38	6.06	**1–3**, 2–3
'Less risk of pollution in organic farming'	6.36	5.88	5.89	6.02	*1–2*, *1–3*
'Organic livestock farming better maintains animals' natural requirements'	5.93	5.84	5.77	5.84	
'Organic livestock farming increases the risk of underfeeding and malnutrition'	2.27	2.79	2.26	2.49	*1–2*
'Without herbicides weed problems increase'	2.62	3.24	2.89	2.96	

Mean scores on the statements (Likert-type scale from 1 = totally disagree to 7 = totally agree). Ranked in order of declining pro-organic overall mean score.

[1] Significant differences are in italics ($P < 0.10$), normal ($P < 0.05$) or bold ($P < 0.01$), based on *t*-tests.

profitable than conventional agriculture, the organic sector will also attract attention from the pragmatic, profit-oriented farmer and the agribusiness. The new producers will inevitably influence the organic sector.

Dilemmas have thus been created for the organic movement. Some researchers have warned that the movement may be in danger of losing its identity[5–7]. Organic production and marketing seem to be practiced in a more pragmatic and industrial fashion, often called 'conventionalization', weakening some of the distinctiveness of organic vis-à-vis conventional farming. The organic movement is thus gradually being integrated into the established agricultural systems against which it originally rebelled.

Some influential studies exist within a Californian context, with the production of high-value, high-intensity vegetables, fruits and nuts, and where capitalist producers are employing wage labor[5,7]. For decades, California has been at the forefront of agro-industrialization and agricultural intensification. In Norway, the policy environment, natural conditions, social values, farming traditions and enterprise mixes are different, cf. the section on organic farming in Norway.

Even though the agro-industrialization forces are weaker in Norway, some findings in this study identified trends towards more pragmatic forms of organic production and a more business-oriented approach among the new dairy producers. The old guard tended to have a more diverse enterprise mix, and various crops, livestock and poultry to make the farm a self-sustained environment. Later converting farmers were more specialized. Late entrants' dairy herds had higher inputs of concentrates, achieved higher milk yields, and had a higher incidence of veterinary treatments. Few of the new producers used alternative medicine. Farming goals of profit and leisure time increased in popularity among the late entrants. Among the late entrants, a considerable share also seemed to convert because of the prospects of more profitable farming and the additional organic farming payments rather than because of an ideological commitment to organic farming.

Others have described organic agriculture as a useful and complex example of the way in which nature features in food production and consumption[8,9]. Recent examples of the organic movement's resistance against genetically engineered food[29] point to a still critical position to the established agribusiness and food supply systems. Our findings suggest a majority of fairly committed organic dairy farmers in Norway. Livestock and disease management practices tended to be more pragmatic (in relation to the ideals of organic farming) among late entrants, but the greater part of the herds had a moderate or even low milk production per cow. The respondents were not a homogeneous group with regard to their farming goals and motivations for conversion, not even among those who converted at about the same time. Although financial considerations have become quite important for a considerable number of the late entrants' decision to go organic, environmental, food quality, and philosophical concerns were still more widely present as goals and motives. Finally, all groups of farmers held favorable views about the environmental qualities of the organic farming methods, albeit with different strengths of beliefs.

The flexible, pragmatic, environmentally concerned, but not ideologically committed producers seem to share ideas with principles of integrated farming systems. These principles can be conceptualized as a 'third way' or middle course for agriculture between conventional and organic farming[30]. The pragmatists are quite likely to have other values and priorities than the committed farmers in the old guard. Commercially minded farmers, at least in Sweden,

are more critical of the constraints of organic farming standards[26]. They may prefer to lobby for more pragmatic standards of organic production. The evolution of organic standards can have wide-reaching impacts on the organic sector, making a significant difference in determining who can participate in organic production and which methods of production will be used[7].

One limitation of our study is that accounting for differences in a two-by-two fashion using bivariate analyses cannot capture complex patterns of relationships among multiple variables[31]. Application of multivariate techniques would reduce this limitation. For example, characteristics of business-oriented farmers, independent of conversion time, compared to the more idealistic organic farmers could be further examined. Farm management styles can be identified by use of cluster analysis or the Q methodology[24,32]. The latter approach encompasses a particular method of data collection, not used in our survey design. Because we used a one-off survey, the study does not indicate what changes may be occurring among farmers over time. Converting farmers' management practices, goals and attitudes may be more influenced by organic values as they become more experienced with organic farming. On the other hand, the committed, lifestyle-oriented farmers may also turn into business-oriented players themselves. Longitudinal studies with repeated observations over time on respondents would provide answers to such questions. However, even within these limitations, we provide valuable information about shifts in motives, farm and social characteristics, etc. among those converting to organic farming. And in any case, one needs to recognize that such shifts are a typical feature of any diffusion process, and not an inherent shortcoming of those currently converting[12].

The policy and regulatory environment influences development paths in organic farming in a complex, interactive manner together with a range of other social, economic and natural factors. According to Guthman[7], a regulatory structure that only attempts to support a price premium contributes to the erosion of organic practices. In Norway, support programs have so far succeeded in encouraging organic production and simultaneously keeping the small-scale agrarian structure alive. Although the new producers in Norway practice organic farming in a more pragmatic way than the old guard, the intensity in milk production is still rather low. Tensions among organic farmers regarding their views on sound ways of practice farming and marketing must however be expected. Producers going far beyond the organic minimum standards may prefer separate, stricter regulation schemes, to signal a more idealistic farming system. Pragmatic and committed organic producers may react differently to changes in prices, farm policies and organic regulations[33]. In particular, if economic terms become harder, farmers who go organic just for the money may be more likely to return to conventional farming than those committed to broader organic principles.

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Enhancing pork flavor and fat quality with swine raised in sylvan systems: Potential niche-market application for the Ossabaw hog

Charles W. Talbott[1,*], M. Todd See[2], Peter Kaminsky[3], Don Bixby[4], Michael Sturek[5], I. Lehr Brisbin[6] and Charles Kadzere[1]

[1]Sustainable Integrated Systems transforming agriculture (SISta), 293 Rufus Brewer Road, Silver City, NC 27344, USA.
[2]Department of Animal Science, North Carolina State University, Box 7621, Park Hall, Raleigh, NC 27695-7621, USA.
[3]Food and Wine Section, The New York Times, Brooklyn, NY, USA.
[4]American Livestock Breeds Conservancy, Box 477, Pittsboro, NC 27312, USA.
[5]Department of Cellular and Integrative Physiology, Indiana University School of Medicine, 635 Barnhill Drive, Room 385, Indianapolis, IN 46202-5120, USA.
[6]Savannah River Ecology Laboratory, PO Drawer E, Asiken, SC 29802, USA.
*Corresponding author: ChuckTalbott293@aol.com

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Abstract

Our global food supply becomes more vulnerable as we continue to lose diverse genetic resources. The Ossabaw hog is a feral breed that is unique to North America, a distant relative to the renowned Iberian hog and is considered an endangered swine breed. The objective of our farmer participatory project was to examine the meat and fat characteristics of Ossabaw hogs raised in alternative management systems for niche-market application. At one farm, eight Ossabaw pigs were randomly assigned to a grass pasture and fed a free choice corn–soy (CS) ration or placed in a mixed hardwood forest plot and provided free choice peanuts in the shells (P), alfalfa pellets (A) and mast from the mixed hardwoods (diet collectively referred to as PAM). The two diets had no effect on Ossabaw production data or pork quality characteristics; however, fat profiles were altered. Ossabaws weighed approximately 70 kg when harvested at 400 days and produced chops with small loin eyes (21–23 cm^2) and minimal evidence of intramuscular fat deposits (1%). The unsaturated fatty acid (USFA) to saturated fatty acid (SFA) ratio improved from 1.6 to 2.6 ($P < 0.01$) as a result of feeding the PAM diet. Forest-finished Ossabaw pork was considered more flavorful by food critics and renowned chefs than that of conventionally fed animals. Mast from hardwoods offers the possibility of enhancing pork flavor for niche markets and using a renewable forest resource as a food source. For farm two, eight Ossabaw gilts and eight crossbred progeny (from European breeds) were randomly assigned to one of the two dirt-lots and fed free choice a CS ration or PA diet (same ration as mentioned above with no mast). Ossabaw hogs grew nearly one-third as fast as the crosses and weighed approximately 80% of the crosses' harvest weight at twice their age. Loin eye areas of the crosses were nearly twice as large as the Ossabaws while the subcutaneous back fat deposition was nearly half. Compared to the CS diet, the PA ration decreased SFA by 23% while polyunsaturated fatty acids (PUFA) increased by 60%. The USFA to SFA ratios improved from 1.5 to 2.2 ($P < 0.01$) when PA diets were fed. Differences ($P < 0.05$) in USFA profiles were observed for breed effects; Ossabaws had 8% higher levels of monounsaturated fatty acids and 18% lower PUFA levels than the crosses. When adjusted for breed effects, no differences in sensory characteristics for the CS versus PA diets were detected by a trained panel. Ossabaws were more flavorful than the crosses (2.3 versus 1.6); ($P < 0.05$).

Key words: Ossabaw hogs, endangered breeds, niche markets, alternative diets, mast, sylvo-pastoral, healthy pork

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Introduction

The theme for the 21st World Food Day Teleconference (broadcast by satellite on October 15, 2004) was 'Biodiversity for Food Security'. Nearly 75% of all agricultural crops and over 20% of livestock breeds are endangered or already extinct[1]. The corporate agribusiness model typically replaces indigenous, less productive strains of plants and animals with those that are more productive, but which require high inputs. Other factors involve the economic forces of globalization and the utilization of the few, more productive indigenous stock in crossbreeding programs with exotic breeds[2]. Our global food supply becomes more vulnerable as we lose possible genetic resources that may be able to adapt to environmental changes or to the introduction of new pests and diseases. Biotechnology cannot regenerate genetic diversity if it is lost[3].

Land grant universities and research stations have assisted in developing and promoting animal efficiency and productivity by optimizing the housing environment and identifying diets and breeds of animals suited for confinement rearing. Consequently, a reliance on a few breeds that perform efficiently indoors and conform to industry standards further decreases the potential for conserving the majority of breeds that do not fit the agribusiness model. The 30-year transformation of the hog industry from pastured systems to confinement rearing is a prime example of this trend[4]. Out of the 19 swine breeds that are listed by the American Livestock Breed Conservancy (ALBC) and are registered by breed associations in North America, six are considered on the critical list (<200 registrations) and two are classified as threatened (<1000 registrations)[5].

The Ossabaw Island hog is a feral breed that is unique to North America and is considered on the ALBC critical list. Ossabaw hogs are descendents of Iberian hogs with few introductions of genes from other swine populations[6]. They derive their name from the Georgia barrier island they inhabit. During their early explorations, the Spanish brought pigs to the Americas that escaped or were deliberately set free in order to stock their future colonies[5,6]. These pigs became the foundation of historic swine populations (both domestic and feral) in the Southeast. For over 400 years, Ossabaws have been naturally selected to thrive in an island ecosystem characterized by cyclic starvation due to variations in food supply, principally a fall acorn mast crop. Consequently, Ossabaw hogs have the ability (a thrifty genotype) to efficiently deposit stores of fat when the food supply is plentiful[7] and have also developed a tolerance to high levels of dietary salt which allows them to forage in and drink from brackish marshes[8]. This 'thrifty genotype' is common to pigs and humans. It is also known as 'metabolic syndrome' or 'prediabetes' in humans and, when coupled with inactive lifestyles and a continuous, plentiful food supply in modern times, results in full-blown type 2 diabetes. The near epidemic of obesity and type 2 diabetes in the United States is of keen interest to the medical community[9–11]. A comprehensive study on feral swine behavior examines the impact of the Ossabaw and the barrier island ecology[12,13].

With all its unique biological characteristics, the future status of the Ossabaw hog is threatened as they pose an environmental challenge to the ecology of the island. Pigs are easily adapted to a wide range of environments, and with no significant predators other than alligators, the Ossabaw hog population becomes unmanageable with consequences for other plant and animal life. The Georgia Department of Natural Resources is responsible for managing Ossabaw Island, and their current policy is that the pigs should be controlled by shooting and trapping, with the goal being to reduce the population to the lowest level possible[14]. Justification for preserving a breed typically depends upon its economic importance or niche[2]. Limited information is available regarding the Ossabaw meat quality characteristics for niche-market application.

Producing the 'four legged olive tree'

Iberian hams are produced from Iberian hogs in the southwest region of Spain. At 12 months of age, the hogs graze acorns ($2\,\text{hogs}\,\text{ha}^{-1}$) and native grasses exclusively for 2–3 months or until they reach approximately 160 kg. The unique aromatic flavors of the Iberian hams are attributed to a variety of volatile compounds and high levels of amino acids, produced from both the feeding regime of the hogs and aging process of the hams[15]. Iberian hogs are given free range of the oak and pasture lands, during which time the considerable quantity of mast and late season grasses available in the fall enable the hogs to put on 40% of their slaughter weight, all of it high in monounsaturated fats (62%) and antioxidants[16]. When the Iberian hog is raised in this system, the locals call it the 'four legged olive tree', as the pork fat contains high levels of oleic acid which is found in olive oil. The resultant meat, full of intramuscular fat, produces hams that can age for 2 or more years without desiccation. Like a long aged wine, these hams develop deep flavor. Fetching prices in excess of 77 Euros per kilo (US$35 per lb) in fall 2004, the Iberico ham industry alone is a billion dollar business.

Producing 'healthy pork' because 'pigs are what they eat'

Before 1950, nearly one-third of all acres grown for peanuts in the US were used by pigs to 'hog down' in the fall[17]. When pigs are fed peanuts instead of corn, increases in the level of unsaturated fats (oleic and linoleic) and subsequent decrease in the levels of saturated fats (palmitic and stearic) are observed[18]. After cooking, the palatability and attractiveness of the soft (lard) pork are similar to that of hard (lard) pork. In eastern North Carolina, farmers used to turn their hogs into peanut fields to glean residual produce and then finish them on corn for the last 6 weeks to harden the fat. This practice enabled the farmer (and eventually packers) to store fresh pork longer due to the higher

incidence of the harder (saturated fats) lard produced from feeding corn. Several studies have shown how levels of fatty acid saturation in swine tissues can be influenced by feeding diets high in unsaturated fats[19–21]. Currently, farmers are typically penalized for carcasses that have soft (unsaturated) fats. Saturated fats are less likely to oxidize than unsaturated fats and therefore assist in keeping the quality of meats. However, saturated fats are less desirable for health-conscious diets because of their positive association with blood cholesterol levels and heart disease[22]. Human diets that include higher intakes of unsaturated fats tend to produce blood profiles with lower levels of low-density lipoprotein (LDL) cholesterol, a precursor to hypertension and heart disease. In a crossover study involving 20 women, lower levels of total plasma and LDL cholesterol were observed after consuming pork containing higher levels of polyunsaturated fats[23]. Pork with higher levels of unsaturated fats could be marketed similar to the way fresh fish is marketed: meat that promotes a healthy diet of unsaturated fats and requires a shorter shelf life.

Rejuvenating old oak forests

Many species of swine evolved in sylvan environments where cooler temperatures provided by a natural canopy aid in thermoregulation during the warm seasons. Sows raised in a sylvan environment during the hot, humid North Carolina summers may be more productive than those raised in a conventional dirt lot environment. Heat stress has been shown to decrease estrus activity, fertility, ova implantation and overall reproductive efficiency of the sow[24]. Soil surface temperatures in wooded lots were 13.5°C cooler than those observed in dirt lots[25]; sows gestating in wood lots versus open-dirt lots with wallows ($n = 70$) during warm seasons tended to produce 0.3 more pigs per litter at farrowing and weaned 0.6 more pigs at 42 days. The woods also supply a vast amount of nutrients in the form of nuts/mast from forest canopies, roots and tubers, and carrion. Appalachian farmers and homesteaders typically ear notched their 150–200 hogs to harvest chestnuts and acorns from the 'open range' woods[26]. Chestnut-fed hogs produced the 'sweetest meat' but rendered into a dark oil instead of a white lard. Some acorns produced bitter-tasting pork and altered fat consistency. The Iberian model offers credence to niche-market application whereby swine purposely harvest tree mast (acorns) to provide a unique flavor and fat profile of the meat.

There are few references regarding managed studies of swine in sylvan ecosystems to improve an existing timber stand or help to establish a more marketable one. Managing hogs in the woods is a dynamic 'put and take' system and requires careful monitoring to realize the owner's forest management plan. Tree growth response or destruction depends on the animal stocking rate and duration of their stay. Preliminary studies with gestating sows in wood lots during the warm season in North Carolina (two 6-month seasons, April 1–September 30) suggest potential for improving hardwood timber stands by reducing vegetative competition. Depending on stocking density (12 or 36 ha^{-1}) and duration of placement, sows tended to girdle soft woods and leave hard woods (except elms) intact; 70% of the under-story vegetation was removed[25]. Similar to 'Old Oak Savannas', grass production offers an additional feed source to tree mast as the canopy opens up and more light reaches the forest floor. By moving sows to new sylvan lots (both seasonally and/or when forest management goals are achieved), farmers may gradually improve their existing, non-marketable timber stands with wood products of higher market value.

Figure 1. Emile DeFelice with Farmer's Hybrid crosses in red and white oak forest (photo by Peter Kaminsky).

The main objective of our project was to examine the meat and fat characteristics of Ossabaw hogs raised in alternative management systems for niche-market application. The Ossabaw hog is the closest North American relative of the renowned Iberian hog but with 400 years of natural selection on a harsh, isolated oak hammock barrier island. The long-term goal of our research is to identify economical characteristics of this unique genetic resource and offer sustainable options to promote small-scale farms.

Materials and Methods

Participating farms and animal feeding treatment groups

Sixteen Ossabaw gilts were acquired in collaboration with M. Sturek at the University of Missouri and were placed at one of the two farms to conduct farmer participatory research. An important aspect of this project funded by USDA SARE, was to involve innovative farmers who have the resources (wood lots and dirt lots or pastured lots), an interest in preserving genetic resources, and a talent for direct marketing. Emile DeFelice's Caw Caw Creek Farm is located at St. Mathews, South Carolina and was chosen for trial one. DeFelice raises Large Blacks, Farmer's Hybrid composites (Fig. 1) and now Ossabaws (Fig. 2). At Caw Caw Creek Farm, eight Ossabaw pigs were

Figure 2. Ossabaw gilts in pasture lot 'protecting' Emile DeFelice (photo by Chuck Talbott).

Figure 3. Ossabaws grazing at forest's edge (photo by Chuck Talbott).

randomly assigned to one of DeFelice's grass pastures (100 m × 100 m) and fed a free choice CS (16% CP) ration or placed in a mixed red and white oak forest plot (200 m × 300 m) and provided *ad libitum* peanuts (P) in a shell (90% DM), alfalfa pellets (A), a dry cow mineral mix (for inclusion of high levels of the antioxidants vitamin E and Se) and mast (M) from the mixed hardwoods (diet collectively referred to as PAM; see Fig. 3). In order to more closely replicate the Iberian hog system, Ossabaws were placed in their respective treatments at an average age of 333 days and remained there for 68 days.

Eliza MacLean's Cane Creek Farm in Saxapahaw North Carolina was chosen for trial two because of her interest in preserving genetic resources; she currently raises crosses of Tamworth, Farmer's Hybrid and Ossabaw (see Fig. 4). MacLean also has a direct marketing association with haute cuisine restaurants in the area known in North Carolina as the Triangle (Raleigh, Chapel Hill and Durham). Eight Ossabaw gilts and eight progeny (TD × FH) from the matings of Tamworth × Duroc sows (TD) with Farmer's Hybrid (FH) boars (a hardy composite breed of Duroc, Hampshire, Chester White, Large White and Spot) were randomly assigned to one of the two dirt lots (100 m × 100 m) and fed *ad libitum* a 16% CP CS ration or peanuts (P) in the shell (90% DM), alfalfa pellets (A) and a dry-cow mineral supplement (mentioned in trial one). Pigs in trial two were given the diets for 42 days and averaged 305 and 140 days of age for the Ossabaws and TD × FH crosses respectively. Because differences in growth rate or feed efficiency were not of primary interest, no attempt was made to balance the caloric or nitrogenous intakes; the primary purpose of the investigation was to examine pork quality characteristics of the diets and breeds and modify fatty acid profiles. Fatty acid profiles from the diets in both trials are listed in Table 1.

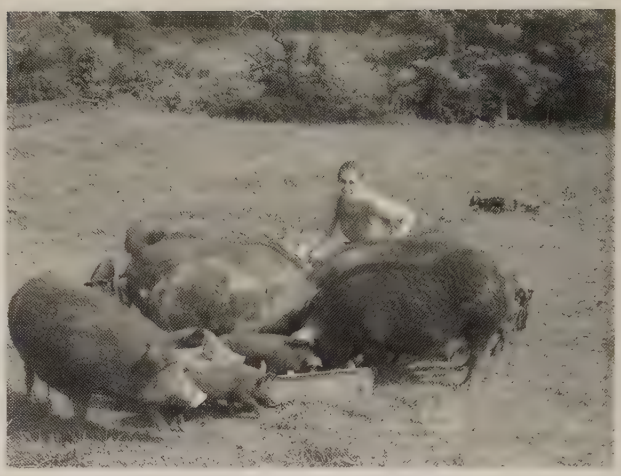

Figure 4. Eliza MacLean with Ossabaw sows and litters (photo by Chuck Talbott).

Pork characteristics and fat profiles

Pigs were rested a minimum of 6 h at the packing plant and slaughtered by electrical stunning. Twenty-four hours post-mortem, carcasses were fabricated into primal cuts and the right loin from each pig was collected. One chop was collected from each loin at a location between the 10th and 11th ribs and allowed to bloom for 20 min. Each loin chop was scored visually for color, using a scale from 1 (pale) to 6 (very dark) and intra-muscular fat, using a scale from 1 (devoid) to 10 (abundant) by trained personnel according to National Pork Board standards[27]. Fat depth was measured using a steel ruler at a point three-fourths of the distance along the loin muscle, and loin muscle area was determined using a plastic grid (AS-235e, Iowa State University, Ames, IA, USA) placed on the cross-sectional surface. Ultimate pH was measured at 24-h post-mortem using an NWK Binar pH meter (Landeberg, Germany). The pH of the raw sensory sample was determined on the whole muscle using a Model HI 9025 Hanna Instruments pH meter with a Hanna Instruments Model FC 200 Combination electrode. Before using, the pH meter was calibrated with both pH 4.0 and 7.0 buffer. Visual scores were subjectively evaluated using the 1–6 scale Japanese Color Bar.

Table 1. Fatty acid profiles (%) of diets fed to Ossabaws and Farmer's Hybrid crosses.

			% Fatty acids from diets		
Common name	**Fatty acid**	**CS**	**Peanuts with shells**	**Acorns**	**Alfalfa pellets**
Myristic	C14:0	0.14	0	0	1.6
Palmitic	C16:0	12.7	11.6	11.8	1.1
Palmitoleic	C16:1	0.5	0	0.17	21.4
Stearic	C18:0	1.7	2.3	2.7	4.0
Oleic	C18:1	24.9	47.3	49.6	6.2
Linoleic	C18:2	56.3	32.0	29.9	22.3
Linolenic	C18:3	3.2	1.6	1.6	37.6
Arachidic	C20:0	0.23	1.2	0	1.5

Loin chops were shipped frozen to the Iowa State Animal Science Department (313 Kildee Hall, Ames IA, USA) for fatty acid analysis. Total lipids from the muscle were transmethylated using $NaOCH_3$/methanol for 15 min at 50°C[28]. The free fatty acids of the diets were methylated with trimethysilyldiazomethane at room temperature for 30 min[29]. The fatty acid methyl esters (FAME) were extracted with hexane, and analyzed by GC equipped with an autosampler, a flame ionization detector and an SP-2560 fused silica capillary column (100 m × 0.25 mm i.d. × 0.2 µm film thickness) (Supelco Inc., Bellefonte, PA, USA). Helium was the carrier gas at a split ratio of 1 : 30. The injector and detector were maintained at 250°C. A temperature-programmed procedure was used[29]. In brief, the column was operated at 70°C for 4 min, and then was programmed to 175°C at 13°C min^{-1}, held there for 27 min, followed by a second temperature program to 215°C at 4°C min^{-1}, and held there for 27 min. The total running time was 76.69 min. Peaks of FAME were identified by comparing the retention time with the GLC and CLA standards purchased from Nu-chek-Prep, Inc. and Matreya Inc. The fatty acid compositions were calculated using the peak areas on a percentage basis.

Sensory evaluation

Through professional association with Peter Kaminsky (a food and wine writer for the *New York Times*), some of the best chefs and food critics on the East Coast were asked to evaluate the forest-finished and pasture-raised Ossabaws used in trial one. Chilled carcasses were shipped to New York City and Virginia for preparation by Daniel Boulud (Daniel's), Thomas Keller (The French Laundry), Fabio Trabocchi (Maestro), Donna Lennard and Ed Witt (Il Buco), and Peter Hoffman (Savoy). For trial two, chops were shipped frozen to the Iowa State University Food Science Lab for evaluation by three trained panelists. Twenty-four hours prior to analysis, samples were placed in a 2–4°C cooler to thaw. Thawed chops were removed from the bag and the loin muscle removed from the bone. Both boneless loin chops from each sample were simultaneously broiled to 71°C in an electric oven broiler (Amana Model ARE 640) preheated to 210°C. Temperature of each chop was individually monitored using thermocouples (Chromega/Alomega, 0.02 dia, 72 inch) attached to an Omega digital thermometer (Model DSS-650, Omega Engineering). The broiled sensory chop was evaluated by a three-member, highly trained professional sensory panel. During training, panelists were served broiled loin samples displaying various intensities of juiciness, tenderness, chewiness, pork flavor and off-flavors. For the test, the broiled loin chop was cut such that three, 1.3-cm cubes were removed from the center of the chop. Each panelist was presented with one warm cube in individually coded glass petri dishes for evaluation of juiciness, tenderness, chewiness, pork flavor and off-flavor using a ten-point category scale. The scale was anchored on the left end with a term representing a low degree of juiciness, tenderness, chewiness, flavor and off-flavor intensity. On the right end of the scale was a term representing a high degree of the characteristic. Room temperature deionized distilled water and unsalted crackers were used to cleanse the palate between samples.

In trial one, data were analyzed using a two-sample *t* significance test to compare Ossabaw characteristics fed different diets[30]. For trial two, a General Linear Models procedure of SAS[30] was performed using a 2 × 2 Factorial Design representing the two diets and breed groups represented.

Results and Discussion

Ossabaw hogs were approximately 11 months old and weighed 50 kg when trial one began (see Table 2). After 400 years of natural selection, the Ossabaw hog weighs half (80 kg versus 160 kg) as much as its distant relative, the Iberian hog at similar harvest ages. The two diets had no effect ($P>0.5$) on Ossabaw performance for average daily gain or loin eye muscle area, back fat, pH, meat color and intramuscular fat visually assessed (Table 2). When harvested at 400 days of age, Ossabaws weighed approximately 70 kg and produced chops with small loin eyes (21–23 cm^2) and minimal evidence of intramuscular fat deposits (1%). Another example of this type of survival metabolism is observed in the Mukota pig of southern Africa. The Mukota pig thrives in adverse nutritional environments and has a thick subcutaneous fat layer that

Table 2. Production data and carcass characteristics of Ossabaws and Farmer's Hybrid crosses (TD × FH) fed CS, peanuts (P), mast (M) and/or alfalfa (A) diets.

	Trial 1 Ossabaws			Trial 2 Ossabaws and TD×FH				
	Diets			Diets for Ossabaws		Diets for TD×FH		
Trait	CS ($n=4$)	PAM ($n=4$)	(SE)	CS ($n=4$)	P/AL ($n=4$)	CS ($n=4$)	PA ($n=4$)	(SE)
Age start trial (days)	333	334	(17)	321[c]	290[c]	142[d]	142[d]	(6.4)
Weight start trial (kg)	52	53	(2.2)	69	66	68	68	(4.8)
Days on experiment	68	68	(0.0)	42	42	42	42	(0.0)
Harvest weight (kg)	68	71	(3.1)	81[c]	78[c]	102[d]	102[d]	(5.9)
Harvest age (days)	401	402	(17)	362[c]	331[c]	183[d]	183[d]	(6.4)
Average daily gain								
Birth to harvest (kg/day)	0.17	0.18	(0.008)	0.22[c]	0.23[c]	0.56[d]	0.63[d]	(0.024)
Trial period (kg/day)	0.24	0.27	(0.029)	0.32[c]	0.30[c]	0.86[d]	0.98[d]	(0.055)
Loin eye area (cm^2)	23	21	(0.6)	22.6[c]	20.0[c]	38.1[d]	37.4[d]	(6.45)
Back fat (mm)	45	43	(1.8)	55.9[c]	48.3[c]	27.9[d]	22.9[d]	(0.12)
pH	5.6	5.6	(0.04)	6.3	6.0	6.0	6.0	(0.11)
Color (visual)	4	4	(0.14)	3.75[c]	4.25[c]	2.5[d]	3.0[d]	(0.31)
Intramuscular fat (visual, %)	1	1	(0.0)	1.75	1.75	1.25	2.0	(0.46)

[c,d] Estimates with different superscripts are significantly different ($P < 0.01$).

appears to have also evolved at the expense of intramuscular fat[31].

With approximately 50 mm of back fat, the question arises as to why conditions for survival should favor subcutaneous deposition of fat exclusively over some modest deposition of intramuscular fat. It should be noted, however, that a major factor in the thrifty genotype is simply being able to store fat most efficiently and then mobilize the fat from stores for energy (as free fatty acids). Internal fat depots, i.e. visceral fat depots, are mobilized first to liberate fatty acids[7] and it must be appreciated that Ossabaw pigs have plentiful visceral fat, as documented with computerized tomography[9].

The fatty acid profile changes in Ossabaw loins were not as pronounced as in subcutaneous fat. The linoleic acid content in the loin increased 43% from 10.1 to 14.4% (Table 3) as a result of feeding the peanut, mast and alfalfa (PAM) diets. In the subcutaneous adipose tissue, the PAM diet lowered the SFA levels by 28% from 39.3 to 28.1%, while it increased the monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) by 13 and 36% respectively. The USFA to SFA ratio improved ($P < 0.01$) from 1.6 to 2.6 as a result of feeding the PAM diet. This finding may be of importance to food outlets and chefs that exclusively use animal fat as the principle cooking fat source. In preparing food, the carcasses from Ossabaw hogs fed PAM diets may enhance human cardiovascular health due to the benefits associated with consuming diets that are higher in USFAs. This finding supports one of the objectives of this study that is tied to attempting to develop a niche market for Ossabaw pork with diet-influenced fatty acid profiles.

Forest-finished Ossabaws were cooked at a number of tastings for renowned chefs, food critics and writers. Without question and without exception, the entire group of chefs and food writers over the course of numerous tastings in December, January and February (i.e., the peak acorn eating months) found the forest-finished Ossabaw pork vastly superior to pork from the conventionally fed animals. 'Deeper, more complex,' were the common terms used to describe the pork. Meat cuts that had more fat deposited in the seams (i.e., shoulder) and braised for extended periods, had both deep flavor and deep taste.

In trial two, the Ossabaw hogs grew nearly one-third as fast as the TD × FH crosses and weighed approximately 80% of the crosses' harvest weight at twice their age (Table 2). Loin eye areas of the TD × FH crosses were nearly twice as large and subcutaneous back fat deposition nearly half that observed in the Ossabaws. Despite the well-marbled (3.6%) loin characteristics of the Farmer's Hybrid[32], the lack of intramuscular fat deposits from the TD × FH crosses used in this study reflects more the lean characteristics inherited from the TD sows[4].

When the peanut and alfalfa (PA) diet was substituted for the CS ration, SFAs decreased 23% while PUFAs increased 60% (Table 4). Unsaturated to saturated ratios improved ($P < 0.01$) 47% from 1.5 to 2.2 when PA diets were fed. After adjusting for diet effects, differences ($P < 0.01$) in unsaturated fat profiles were observed for breed effects; Ossabaws had 8% higher levels of MUFAs and 18% lower PUFA levels than TD × FH crosses. Similar breed differences in intramuscular fatty acid profiles were reported for Iberian versus Landrace breeds, fed with diets consisting of maize versus acorn–sorghum–maize diets[33].

Regardless of diet, intramuscular fat deposits were < 2% for both breed groups and may reflect the less than enthusiastic sensory responses recorded by the trained panel. When adjusted for breed effects, no differences were

Table 3. Percentage of fatty acids (%FA) in loin or adipose tissue of Ossabaws fed CS or PAM diets fed in trial 1.

Fatty acid	% FA from loin			% inc+/dec− PAA versus CS	% FA from adipose			% inc+/dec− PAM versus CS
	CS	PAM	(SE)		CS	PAM	(SE)	
C14:0	1.5	1.4	(0.12)	−9	1.4[c]	0.7[d]	(0.13)	−49
C16:0	23.9[a]	22.6[b]	(0.27)	−5	24.6[c]	17.4[d]	(0.95)	−29
C18:0	10.4	9.5	(0.55)	−9	13.1[a]	9.6[b]	(0.88)	−27
C20:0	0.16	0.41	(0.091)	156	0.21[c]	0.35[d]	(0.021)	67
Total SFA	36.0	33.9	(0.78)	−6	39.3[c]	28.1[d]	(1.75)	−28
C16:1	3.8	3.0	(0.27)	−23	1.8[c]	1.0[d]	(0.06)	−42
C18:1	43.1	46.2	(1.52)	7	42.8[c]	49.1[d]	(0.71)	15
C22:1	0.17[a]	0.12[b]	(0.016)	−29	0.05	0.1	(0.04)	100
Total MUFA	47.1	49.3	(1.70)	5	44.6[c]	50.2[d]	(0.68)	13
C18:2	10.1[a]	14.4[b]	(1.09)	43	14.5[a]	19.8[b]	(1.31)	37
C18:3	0.64	0.69	(0.097)	8	0.8[c]	1.1[d]	(0.06)	41
C20:2	0.24	0.26	(0.013)	8	0.62	0.64	(0.95)	3
C20:3	2.1	1.5	(0.41)	29	0.16	0.16	(0.03)	0
Total PUFA	13.1	16.9	(1.48)	29	16.0[a]	21.8[b]	(1.42)	36
Unsaturated: saturated ratio	1.7	2.0	(0.07)	18	1.6[c]	2.6[d]	(0.21)	63

[a,b] Estimates with different superscripts are significantly different ($P < 0.05$).
[c,d] Estimates with different superscripts are significantly different ($P < 0.01$).

Table 4. Percentage of fatty acids (FA) from loin tissue of Ossabaws (O) and Farmer's Hybrid crosses (TD × FH) fed CS or PA diets in trial 2.

Fatty acid	Adjusted FA means for diet effect				Adjusted FA means for breed effect			
	CS diet ($n = 8$)	PA diet ($n = 8$)	(SE)	% inc+/dec− for PA versus CS	TD×FH ($n = 8$)	O ($n = 8$)	(SE)	% inc+/dec− for O versus TD×FH
C14:0	1.6	1.2	(0.15)	−26	1.5	1.3	(0.15)	−10
C16:0	26.0[d]	20.5[c]	(0.95)	−21	23.6	22.9	(0.94)	−3
C18:0	12.3[d]	8.9[c]	(0.38)	−28	10.5	10.7	(0.38)	+2
C20:0	0.19	0.26	(0.031)	37	0.19	0.26	(0.03)	37
Total SFA	40.3[c]	31.0[d]	(1.15)	−23	35.4	35.9	(1.15)	1
C16:1	3.2[c]	2.0[d]	(0.18)	−37	2.4	2.8	(0.18)	17
C18:1	43.1	44.9	(0.74)	4	42.6[c]	45.5[d]	(0.74)	7
Total MUFA	46.5	47.8	(0.69)	3	45.3[c]	49.0[d]	(0.69)	8
C18:2	10.7[c]	18.6[d]	(0.76)	75	16.4[c]	12.9[d]	(0.76)	−21
C18:3	1.1	1.2	(0.12)	2	0.96	1.3	(0.12)	36
C20:2	0.37	0.46	(0.045)	24	0.39	0.44	(0.04)	13
C20:3	0.06	0.07	(0.023)	17	0.07	0.06	(0.023)	−14
Total PUFA	13.2[c]	21.1[d]	(0.79)	60	18.8[c]	15.5[d]	(0.79)	−18
Unsaturated: saturated ratio	1.5[c]	2.2[d]	(0.10)	47	1.9	1.8	(0.10)	−5

[c,d] Estimates with different superscripts are significantly different ($P < 0.01$).

detected in sensory characteristics by the trained panel for the CS versus PA diets (Table 5). Similar sensory observations were reported for other experiments comparing crossbred hogs fed peanut versus CS diets[34]. However, breed differences were observed by the trained panel (Table 6). Compared to the TD × FH crosses, Ossabaws were more flavorful (2.3 versus 1.6) and had more (dark turkey meat) off-flavors (3.3 versus 1.5) than the TD × FH crosses, respectively.

The comments by both groups of expert panelists (chefs and food critics in trial one or ISU Food Science Lab in trial two) were informative. The former attributes the forest-finished Ossabaws as having 'a deeper, more complex flavor', which may be another way of defining the off-flavor (dark turkey meat) distinction, assigned to the Ossabaws by the ISU group. Dark turkey meat is generally considered very flavorful due to the predominance of red muscle fibers and intramuscular fat deposits. The ISU group

Table 5. Least squares means[1] for diet effects in sensory characteristics[2] of loin muscle adjusted for breed.

	Sensory characteristics					
Diet	**Juiciness**	**Tenderness**	**Chewiness**	**Pork flavor**	**Off-flavor (sour)**	**Off-flavor (dark turkey meat)**
CS	4.7 ± 0.4	5.0 ± 0.4	3.0 ± 0.3	1.7± 0.2	3.7 ± 0.2	2.2 ± 0.5
PA	4.2 ± 0.4	4.2 ± 0.4	4.1 ± 0.3	2.2 ± 0.2	3.5 ± 0.2	2.6 ± 0.5

[1] Animal per treatment = 8; panelists = 3.
[2] Ten point category scale; juiciness: 1 = dry, 10 = juicy; tenderness: 1 = tough, 10 = tender; chewiness: 1 = not chewy, 10 = very chewy; pork flavor: 1 = none, 10 = intense; off-flavor: 1 = none, 10 = intense.

Table 6. Least squares means[1,2] for breed effects in sensory characteristics[3] of loin muscle adjusted for diet.

	Sensory attributes					
Breed	**Juiciness**	**Tenderness**	**Chewiness**	**Pork flavor**	**Off-flavor (sour)**	**Off-flavor (dark turkey meat)**
TD × FH cross	4.4 ± 0.4	5.0 ± 0.4	3.0 ± 0.3	1.6^{a} ± 0.2	4.0 ± 0.2	1.5^{a} ± 0.5
Ossabaw	4.5 ± 0.4	4.2 ± 0.4	4.1 ± 0.3	2.3^{b} ± 0.2	3.2 ± 0.2	3.3^{b} ± 0.5

[1] Means in a column followed by a different superscript are significantly different ($P < 0.05$).
[2] Animals per treatment = 8; panelists = 3.
[3] Ten point category scale; juiciness: 1 = dry, 10 = juicy; tenderness: 1 = tough, 10 = tender; chewiness: 1 = not chewy, 10 = very chewy; pork flavor: 1 = none, 10 = intense; off-flavor: 1 = none, 10 = intense.

uses the confinement hog as an ideal model to measure the pork sensory characteristics; any deviation from this model is attributed as 'Off Flavor'. For niche-market application, a new 'On Flavor' classification may be required to distinguish differences in conventional sensory models.

Conclusions and Observations

We achieved our major goal of comparing the meat and fat characteristics of Ossabaw hogs raised in alternative management systems for niche-market application. There were major improvements in fatty acid profiles from SFA to MUFA and superior taste was noted in the Ossabaws raised in the sylvan system. The implications for 'heart healthy' pork that may reduce cardiovascular risk factors and pre-diabetes in humans are very promising.

Based on the results from this study, commercial production of purebred Ossabaws is tenuous with their slow growing ability (< 0.19 kg per day average daily gain from birth to harvest) and lack of optimum pork quality characteristics, mainly small loins with minimal intra-muscular fat deposition. Unpublished results of Ossabaw sows crossed with Farmer's Hybrid boars suggest high levels of hybrid vigor expressed for maternal traits, growth and carcass traits. Further work is warranted.

Many of the chefs and consumers supporting small-scale farmers simply value the superior niche-market product[35]. Many are also interested in the way the animals are raised (space allotted per animal; indoors versus pastured) and concerned about the diets the animals are given (i.e., animal byproducts, sub-therapeutic levels of antibiotics, growth stimulants). A few project farmers are currently receiving $9–10 per kg ($4.00–4.50 per lb) for their whole pork carcasses from haute-cuisine chefs. This price is very competitive compared to beef carcasses ($16 per kg or $7.25 per lb for loins and shoulders), lamb carcasses ($24 per kg or $10.90 per lb) and fish ($24 per kg or $10.90 per lb). The bargain is accentuated if the lard is used in cooking.

What the future holds for Ossabaws remains to be seen in coming years. However, a serendipitous finding of our study is that pigs raised in a sylvan setting re-emphasize the possibility of using a renewable forest resource as a food source for animal husbandry. To the provocative Buffalo Commons[36] idea of returning the prairie to grazing animals, pigs managed properly in wooded systems may be a method of re-establishing oak park savannas, such as those found in the Southeast at the time when Columbus arrived in the New World.

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Strategic market planning for value-added natural beef products: A cluster analysis of Colorado consumers

Dawn D. Thilmany[1,*], Wendy J. Umberger[2] and Amanda R. Ziehl[3]

[1]Associate Professor, Department of Agricultural and Resource Economics, B313 Clark Building, Colorado State University, Fort Collins, CO 80523-1172, USA.
[2]Assistant Professor, Department of Agricultural and Resource Economics, B312 Clark Building, Colorado State University, Fort Collins, CO 80523-1172, USA.
[3]Marketing Specialist, Center for Profitable Agriculture, University of Tennessee, P.O. Box 1819, Spring Hill, TN 37174-1819, USA.
*Corresponding author: thilmany@lamar.colostate.edu

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Abstract

In the past decade, sales of meat products labeled as natural (minimally processed) and produced without antibiotics and hormones have increased dramatically. In response to growing demand for meat products differentiated by various production attributes, many smaller-scale beef enterprises are considering direct marketing of their beef products to end-consumers as a viable approach to sustaining their family farming operations. This research uses survey data from Colorado consumers, and factor and cluster analysis to determine market segments for various (varied by production protocols and other meat attributes) natural beef products. Findings from the cluster analysis indicate that there are multiple segments of consumers who are likely to purchase natural beef, and that different segments are motivated by different factors. The most important factor explaining almost two-thirds of the differences among consumer responses relates to consumers' perceptions of the importance of meat attributes related to production practices (e.g. use of antibiotics, hormones and environmentally friendly grazing). Interestingly, the two consumer segments that are willing to pay a significantly higher premium for natural, local beef are motivated by different aspects of the meat and its intrinsic production attributes. One segment, representing 12.5% of consumers, ranked the importance of all production attributes significantly lower than the sample average. Consumers in this segment appear to be motivated by their perceptions of the extrinsic quality of natural beef products. The other segment, 13% of consumers, appears to be altruistic, ranking all production attributes such as 'no antibiotics', 'no hormones', and 'humane treatment', significantly higher than all of the other clusters. These results indicate the potential strength of production methods (and marketing of such quality differences) as product differentiation criteria. This paper illustrates the type of market research that may be useful for beef producers seeking value-added marketing opportunities, and portrays the types of consumers who are fueling the growth in natural meats in the United States. Such market analysis can facilitate producers' ability to effectively develop product concepts, labeling and promotional strategies targeted at the most receptive consumer segments, and illustrates that there is more than one type of consumer interested in purchasing products differentiated by sustainable production methods.

Key words: natural beef, consumer demand, targeted marketing

Introduction

Natural (minimally processed, containing no artificial ingredients or added color[1]) and organic (from animals given access to the outdoors, fed no antibiotics or growth hormones, and produced by farmers who emphasize the use of renewable resources and the conservation of soil and water[2]) meats and poultry continue to garner increased consumer interest and demand. Retail sales trends for this sector indicate it is the fastest growing segment of the $10.4 billion organic food industry, with a growth of 77.8% between 2002 and 2003[3]. Part of the growth has been due to access and sales of organic food through general supermarkets (rather than specialty natural markets). Sales through mass merchandisers more than doubled from 1993 to 1995 (an increase from $98 to $210 million) and

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accounted for 45% of natural/organic food sales in 2001[3]. These trends illustrate the growing mainstream appeal of natural and organic foods.

The increasing complexity of consumer food purchasing trends is an important factor guiding all agribusiness-marketing efforts[4]. Profiling and targeting consumers by demographics or marketing channel may have once been effective, but it appears that natural meat consumers may be increasingly diverse. This is an issue of interest and importance to large agribusinesses, as well as those producers who seek to develop value-added meat products and to market to smaller niches. One area of increasing differentiation relates to the location and types of production methods used to raise the animals. Throughout the United States and Colorado, numerous new business ventures have been initiated to garner either a price premium or more loyal customer base through the marketing of unique production systems to consumer segments. Market research conducted on behalf of Colorado Homestead Ranches (CHR) is presented here in the context of its potential use for market development and further business planning.

The objective of this research is to analyze consumer segments in Colorado based on their interest and willingness-to-pay for various natural beef products (varied by production protocols and potential public good) using cluster analysis. Such an analysis should facilitate producers' ability to effectively develop product concepts, and labeling and promotional strategies targeted at the most receptive consumer segments. The research hypothesis is that there are multiple segments of consumers who are likely to purchase natural beef, and that different segments are motivated by different factors.

Background

CHR began in November of 1996 as a group of five ranches from the Western Slope of Colorado seeking to provide a healthy, quality beef product directly to the consumer. The current strategic position of CHR is to develop a niche, differentiated line of beef products, targeted at consumers who want a consistent quality product, raised on Colorado ranches, with natural production practices. The company strives to grow marketing activities through retained earnings from marketing and processing revenues, while also assuring a premium is returned to each member for the beef animals that are used as inputs, on a per pound basis.

Since 2002, CHR's marketing and business strategies have focused on the development of a diverse set of marketing channels (farmers markets, retail store, restaurant sales) to connect with an increasingly large consumer base in Western Colorado. Beyond the expected revenue and equity gains from integrating added value into their beef products, CHR seeks to manage the risk inherent in livestock price cycles through a fixed return to participating ranches, thereby relying on a loyal and expanding customer base. At this point in time, there is continued sales growth (exceeding 50% annual growth between 2002 and 2004), and CHR hopes to maintain their annual sales growth through modifications of their current marketing strategy. Changes CHR is currently considering are labeling and certification of various production-related meat product attributes, developing alternative pricing strategies, and creating promotional materials used to market CHR beef.

Historically, CHR's marketing and sales strategies were very small-scale and personal, reflecting the direct connections made with consumers through farmers' markets. However, more formal market planning is expected to be necessary as marketing channels continue to expand, and because personal interaction between the ranchers and consumers may not be feasible if sales continue to grow as rapidly as in the recent past.

The primary competition and substitute products for CHR beef can be described with three segments:

1. Generic, unbranded beef marketed through convenient, large-scale supermarkets.
2. Branded beef products, with some combination of genetic, quality, production practice or production location claims, marketed through supermarkets, natural food stores and meat shops. Examples include Coleman, Maverick, Laura's Lean, Oregon Country and Certified Angus Beef. These products are closer substitutes to CHR beef than those in (1), as production practice assurances are provided to consumers. However, these companies rely on larger marketing channels and do little with convenience products such as ready-to-heat entrees and meat sticks.
3. Direct market beef sales by producers at ranch sites, farmers' markets, small retail stores, mail order and the Internet, with most product information communicated and promoted through personal sales relationships. This is the most direct competition with CHR, but there are few other ranches with established markets on the Western Slope of Colorado.

The primary purposes of CHR's market research and planning are to:

1. Segment the market to help target consumer groups with the greatest potential to purchase CHR's beef products.
2. Create a sustainable competitive advantage among the competition by further developing CHR's beef product line based on consumers' interests in various product attributes.
3. Analyze consumer willingness to pay and assess potential market share at various price points for four different beef products—a representative sample of the CHR product portfolio.

CHR markets frozen beef quarters, halves, individual cuts, processed beef products (jerky, meat sticks) and ready-to-heat entrees through several direct marketing channels throughout the Western Slope of Colorado. The meat is differentiated by its production location (beef is produced on five ranches that have a long history of cattle production and environmental stewardship in the Paonia, Colorado area) and practices (beef is raised without the use of antibiotics and hormones). One might describe CHR's

marketing strategy as a unique combination of intrinsic product development (meat quality assurance for a variety of beef products), along with personal sales and service. However, their personal sales strategies are also targeted toward consumers with interests in broader social benefits, including civic agriculture (support of small and local agricultural producers), environmental benefits (practices friendly to the landscape, water and wildlife) and public health concerns (antibiotic and hormone usage in meat production).

Literature Review

There is a growing set of literature on consumer interest in beef with production quality assurances, such as locally raised designations[5,6]. However, only a small share of this existing literature focuses on the existence, size and characteristics of particular consumer segments. Ziehl[7] found that consumers who have previously purchased natural beef or occasionally buy meat at alternative markets (not supermarkets) are more willing to pay a premium for natural products. Consumers' stated importance and interest in attributes such as natural and/or grass-fed production practices, traceability, and tested for Mad Cow Disease also impact their decision to pay a premium for natural, regionally produced beef.

Smith's[8] seminal work on market segmentation is now a common method for strategically developing the marketing mix for a variety of products. Nearly every market has some distinctive segments. Almost all markets are segmented by price and quality issues. Generally, however, price and quality do not provide the most clear or definitive market segmentation. Much stronger segmentation can usually be found through an evaluation of product or service uses and importance of production attributes to various consumers.

Market segmentation and consumer profiling strategies have been used in agribusiness management analysis to understand consumer response to a number of issues. In a segmentation analysis of supermarket consumers, Mangaraj and Senauer[9] found three distinct market segments: Middle Americans (motivated by price and value), Sophisticates (concerned with quality and service), and Time-pressed, Convenience Seekers (with young children and little time). Carlson et al.[10] conducted an analysis focused on where consumers purchase foods (including away from home) and found nine segments that varied significantly by demographics, but did not consider food attitudes.

In a study measuring food safety preferences related to produce, Baker and Crosbie[11] found three segments, one concerned with pesticide use, one concerned with the level of damage to produce (the majority of respondents) and one primarily concerned with price and quality. Baker and Burnham[12] conducted a similar study in 2000 considering genetically modified foods, and again, found three segments. The three clusters, Brand Buyers, Safety Seekers and Price Pickers, were motivated by different concerns, attitudes toward risk and knowledge of genetically modified organisms, but had demographics that were very similar to each other, illustrating that demographics are not always effective market segmentation factors.

Empacher et al.[13] found four clusters of consumers: (1) Well-organized Eco-families who support local and sustainable agricultural practices (civic agriculture), (2) Strugglers, consumers who are low-income and price sensitive, (3) Rural traditionalists, consumers with traditional agrarian values who have historical ties to agriculture, and (4) Professionals, consumers without children and singles in urban areas with a focus on quality and image.

Following Empacher et al.'s[13] focus on social concerns, this study seeks to extend past consumer profiling by considering more of the civic agricultural issues that may motivate natural beef consumers. Sunding[14] asserts that, in addition to consumers' traditional concerns about nutritional content, purity, and freshness, consumers also may value a product more because it addresses a social concern or has a public good aspect, even though the product may not necessarily be 'more valuable' or 'higher quality' than a conventional product. Attributes such as 'free-range', 'organic', 'natural', and 'locally produced' are a few examples of more publicly oriented food attributes, which are now being labeled[1,2,14–16]. Recently, producers have been trying to target consumers who might value food products with attributes that some believe will positively impact the environment, society, or animal welfare[15,16].

A few studies have looked at how consumers value foods that are produced locally[5,17]. A set of earlier studies conducted by Thilmany et al.[18] and Grannis and Thilmany[19] examined the potential market for natural pork and natural freezer beef in the Intermountain West. The present study updates their work, focuses on specific value-added beef products, and further explores the unique consumer segments that are the most likely consumers of natural, local beef.

Data and Methods

The data were collected from a national online survey conducted by the National Family Opinion organization in April 2004. The National Family Opinion organization was directed to obtain a stratified sample ($n \geqslant 800$), representative of the United States Census; and another stratified sample ($n \geqslant 400$), representative of the Colorado Census, with 30% of the Colorado sample or $n \geqslant 120$ respondents from the Western Slope of Colorado. A total of 1840 members of the National Family Opinion organization's online survey database were solicited to take the survey and a total of 1288 responses were returned, providing a 70% response rate. CHR's goal is to remain a local business, and CHR is only interested in marketing to consumers within the state of Colorado. Therefore, to focus the results on the relevant market for CHR, Colorado consumers, the research discussed in this paper only utilizes survey data from the representative sample of 416 Colorado respondents.

Table 1. Summary statistics for the demographic variables ($n = 416$).

Variable name	Description (coding)	Mean	Standard deviation
Age	In years	47.685	14.112
Gender	1 if female, 0 if male	0.721	0.449
Weekly Grocery Expenditures	1 = < $50, 2 = $50–99, 3 = $100–149, 4 = $150–199, 5 = $200–299, 6 = $300–399, 7 = $400–499,	2.317	1.034
City Size	1 = Rural (< 5000) 2 = Small town (5000–24,999) 3 = Small suburban (25,000–99,999) 4 = Large suburban (100,000–249,999) 5 = Metro area (≥250,000)	3.190	1.438
Income	1 = < $22,500 2 = $22,500–39,999 3 = $40,000–59,999 4 = $60,000–89,999 5 = + $90,000	3.070	1.478
Race	1 if Caucasian, 0 if otherwise	0.873	0.334
Hispanic	1 if Hispanic, 0 if otherwise	0.029	0.168
Household Size	Actual number in household, range: 1–7 members	2.344	1.212
Life Stage	1 if single, no children, 0 otherwise	0.221	0.416
	1 if couple, no children, 0 otherwise	0.413	0.493
	1 if children <6 living in household, 0 otherwise	0.103	0.305
	1 if children >6 living in household, 0 otherwise	0.094	0.292

In general, the survey elicited information on consumer shopping behavior, ratings for different beef production attributes (hormone and antibiotic use, grass-fed, traceable to source, and open range), and attitudes about the perceived benefits (private, public environmental or public health benefits) of different attributes. In addition, a contingent valuation method was used to elicit consumer willingness to pay for natural, regionally produced beef. The beef products considered were two relatively unprocessed products (ground beef and ribeye steaks) and two convenience entrée products (chili verde and beef stroganoff), and were based on product lines carried by the natural meat producers who supported this study with a USDA Value-Added grant, and our interest in whether different segments were interested in basic or convenience entrée choices. The National Family Opinion organization also provided socio-demographic characteristics for each respondent, which they store in their database.

The summary statistics of the socio-demographic information and other responses are given in Table 1. The sample is comparable to the Colorado population based on the US Census[20] in terms of income, household size, and the percentage of households with children living at home. However, the sample includes fewer minorities, more females, and slightly older respondents than the Colorado averages reported by the US Census. The fact that this sample is predominantly female is consistent with the results of several previous food-based surveys because females are generally the primary grocery shopper in a household[4]. The online survey method may have led to lower minority numbers.

There are countless variables to consider when analyzing consumer behavior, and this issue is increasingly complex in a marketplace that emphasizes consumer choice and product customization as strategies to secure higher market share, customer loyalty and an ability to secure premium prices. One analytical tool for examining consumer preferences and behavior is factor analysis, which allows a business to reduce market factors down to a smaller number of 'factors' that can be used to determine important characteristics motivating purchases. High factor loadings indicate a relatively high amount of variability among consumers' responses that can be explained by specific factors, thereby identifying absolutely important factors, as well as delineating those that jointly influence consumer responses. Subsequently, factor analysis will be the first method used to analyze the data, and results will influence the choice of cluster analysis criteria (although

comparisons of clusters will be based on a broader set of factors).

Market segmentation is the process of grouping a market into smaller subgroups that are not arbitrarily imposed, but instead, are derived from the recognition that the total market is often made up of submarkets (called segments). Segments are homogeneous (i.e. people in the segment are similar to each other in their attitudes about certain variables). Because of this intra-group similarity, consumers within a certain segment are likely to respond somewhat similarly to a given marketing strategy[8].

When enough information is combined to create a clear picture of a typical member of a segment, this is referred to as a buyer profile. A statistical technique commonly used in determining a profile is cluster analysis. Cluster analysis is a class of statistical techniques that can be applied to data that exhibits 'natural' groupings with relatively homogeneous characteristics, but with heterogeneous characteristics relative to objects outside the cluster. Cluster analysis, like factor analysis and multi-dimensional scaling, is an interdependence technique: it makes no distinction between dependent and independent variables. The requirements for successful segmentation are: homogeneity within the segment, heterogeneity between segments, segments that are measurable and identifiable, segments that are accessible and actionable, and segments that are large enough to be profitable. Initial analysis of data indicate that all of these factors are present in these data[7]. For this analysis, we used a *k*-means clustering technique embedded in STATA 7.0[21].

Research Findings

Factor analysis

The results from the factor analysis of Colorado consumers are presented in Table 2. The factors can be described in two ways: by the types of variables that have high loadings, and thus, play an important role in explaining consumer differences, and also, by the absolute amount of consumer variability explained by any one factor. The first factor could be defined as concern about production practices, since it is highly related to a consumer's response to the questions about the importance of almost all beef production attributes. This factor is only slightly influenced by willingness to pay, meat attributes, and past purchases of natural beef, as well as concerns about societal health (issues discussed in more detail below). As a whole, this factor explains 61% of the variability among the Colorado survey sample.

The second most important factor, 2, explains almost 20% of the variability, and appears to be most closely related to willingness to pay (or price sensitivity), with few other loadings greater than 0.10. This variable does seem slightly influenced by past natural beef purchases and societal health concerns as well. The third most important factor, 3, explains about 12% of the variability, and seems closely aligned with traditionally marketed meat attributes, notably a premium brand, fresh, pre-seasoned, ready to eat, nutritional, and is a good value for the price. Additionally, the factor loading for the share of the price premium consumers attribute to personal (private) benefits (versus societal or public health benefits) is higher for factor 3 than for any other factor. The variables with high factor loadings for factor 3 may indicate that a segment of consumers exists who are more interested in personal satisfaction from traditionally marketed meat with quality attributes such as brand, convenience, freshness and nutrition. Finally, factor 4 explains 7%, and appears related to only the production attributes ('no antibiotics', 'no hormones', and 'percentage lean') that influence some consumers' perceptions of the 'health aspects' of the product rather than environmental and animal concerns.

These factors represent little that is informative on their own, but demonstrate how a large number of variables relate to one another and justify the inclusion of these factors in subsequent analyses. Some variables (product attributes) could be considered as a related set; for example, 'no antibiotics', 'no hormones', and 'protect endangered species' have similar loadings for factor 1. However, other variables have unique interpretations depending on the context they are considered within ('no antibiotics' and 'protect endangered species' have counter effects on factor 4), suggesting consumers with mixed feelings. This factor analysis motivates the types of variables included in the subsequent analysis of consumer clusters.

Consumer analysis

The consumer clusters are simply the result of a statistical segmentation process that groups like-minded consumers by their similar perceptions and responses. Simple mean comparisons across a wide range of variables are used to develop statistical descriptions of the clusters of consumers that are likely to be most receptive to CHR's natural and locally produced marketing concept. In particular, we focus on clusters of consumers who are willing to pay the price premium that CHR may need to charge in order to recover higher beef production and direct marketing costs.

The five clusters identified in the cluster analysis vary significantly in means across a wide set of variables, including demographics; therefore, these differences are used to name each cluster. Results of the descriptive statistics for the total sample as well as the five clusters are presented in Tables 3a and b, with the results of pairwise *t*-tests of means reported with superscripts (for example, if Cluster 1 differed significantly at the 95% significance level from Clusters 3 and 5, its mean is denoted with superscript 'c' and 'e').

The first cluster is labeled Quality Seekers, and makes up 52 of the 416 surveyed Coloradans (12.5%). The second cluster is labeled Health and Natural Consumers (55 individuals, or 13.2% of all consumers). These two clusters are akin to Empacher et al.'s[13] Professionals and

Table 2. Factor loadings among Colorado consumers.

Variable	Factor Loadings			
	Factor 1: Production Practices	**Factor 2: Willingness to Pay**	**Factor 3: Brand and Convenience**	**Factor 4: Perceived Health**
Maximum Willingness to Pay (1 to 8, in 10% Price Increments)				
Willingness to Pay for Ground Beef	0.1178	0.6256	0.0804	0.0411
Willingness to Pay for Ribeye Steak	0.1508	0.6923	0.0652	−0.0414
Willingness to Pay for Beef Stroganoff	0.0699	0.8591	−0.0339	0.0128
Willingness to Pay for Chili Verde	0.1267	0.7894	0.0143	0.0264
Weekly Grocery Expenditures	0.0946	0.1063	0.1360	0.0449
Weekly Meat Expenditures	0.0386	0.0217	0.0711	0.0088
Secondary Market for Meat (Supermarket is Primary Market for >95% of Respondents)				
Meat Shop	−0.0739	−0.0103	0.1138	−0.0042
Farmers' Markets	−0.0151	0.0905	0.0474	0.0105
Direct from Producer	−0.1007	−0.0326	−0.0787	0.0577
Internet	−0.0210	−0.0294	0.0294	0.0082
Health Food Store	−0.0708	−0.0818	0.0086	−0.0636
Importance of Product or Meat Attributes (1 to 5, 5 = Most Important)				
Open Range	0.8227	−0.0038	−0.0726	0.0076
No Antibiotics	0.8169	−0.0485	−0.1713	0.3102
No Hormones	0.8253	−0.0434	−0.0876	0.2873
Natural	0.7909	−0.0157	−0.0703	0.1964
Organic	0.7707	0.0895	−0.1290	0.1711
Grass-fed	0.7815	−0.0651	−0.0941	0.1507
Preserve Streams	0.7860	−0.0379	0.0150	−0.3041
Protect Endangered Species	0.8192	−0.0112	0.0228	−0.4687
Humane Treatment	0.7601	−0.0670	0.0036	−0.1208
Traceable from Farm to Consumer	0.6782	−0.0932	0.0555	0.1316
Country of Origin Labeling	0.6066	−0.1132	0.2106	0.0814
USDA Certified Organic	0.6599	0.1333	0.0279	0.1744
Value for Price	0.1217	−0.1918	0.3244	0.0083
Nutritional Value	0.4221	−0.1105	0.3730	0.1189
Percent Lean	0.3536	−0.1123	0.3064	0.2607
BSE Tested	0.4759	−0.0117	0.2911	0.1637
Fresh	0.3370	−0.0756	0.3779	0.0964
Aged >14 days	0.3009	−0.0895	0.1359	0.1135
Boneless	0.2142	−0.0252	0.3757	0.1767
Premium Brand	0.2722	0.0078	0.5496	0.1339
Ready to Heat	0.0831	0.0749	0.3462	−0.0108
Pre-seasoned	0.0252	0.1767	0.3953	−0.0282
Purchased Natural Beef (Yes = 1)	0.2344	0.1598	0.1017	0.1830
Share of Price Premium Designated To Concern About ...				
Personal Benefits	−0.1886	−0.0630	0.1433	0.1110
Broad Societal Benefits	0.0418	−0.0214	−0.0914	−0.2238
Public Health Benefits	0.3149	0.1416	−0.0912	0.1277
Age	−0.0426	−0.3135	−0.0856	0.0641
Gender	0.2679	−0.1140	0.0885	0.1476
City Size	−0.0663	0.0407	0.1495	0.0570

Factor	**Variance**	**Difference**	**Proportion**	**Cumulative**
1	8.2292	5.6055	0.6132	0.6132
2	2.6236	1.6302	0.1955	0.8087
3	1.5732	0.0000	0.1172	0.9259
4	0.9935	−0.5797	0.0740	1.0000

Table 3a. Summary statistics for Colorado consumer clusters.

Variable	Cluster 1: Quality Seekers ($n=52$)		Cluster 2: Health and Natural Consumers ($n=55$)		Cluster 3: Moderate Consumers ($n=123$)		Cluster 4: Empathetic Value Seekers ($n=94$)		Cluster 5: Price Conscious Consumers ($n=92$)		Full Sample ($n=416$)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Maximum Willingness to Pay (1 to 8, 10% price increments)												
Willingness to Pay for Ground Beef	5.63[c,d,e]	1.67	5.25[c,d,e]	1.48	2.56[a,b,d,e]	1.80	1.67[a,b,c]	1.62	1.63[a,b,c]	1.68	2.89	2.28
Willingness to Pay for Ribeye Steak	4.61[b,c,d,e]	1.78	3.69[a,c,d,e]	1.35	1.51[a,b]	1.32	1.23[a,b]	1.36	1.13[a,b]	1.25	2.04	1.87
Willingness to Pay for Beef Stroganoff	3.38[b,c,d,e]	1.86	2.47[a,c,d,e]	1.55	0.67[a,b,d]	0.88	0.44[a,b,c]	0.68	0.55[a,b,c]	0.91	1.17	1.54
Willingness to Pay for Chili Verde	3.17[c,d,e]	1.98	2.76[c,d,e]	1.84	0.67[a,b,d]	0.97	0.59[a,b]	1.09	0.57[a,b]	0.88	1.22	1.64
Secondary Market for Meat (Supermarket Primary for >95%)												
Health Food Store	0.15[b]	0.36	0.29[a,c,d,e]	0.45	0.09[b]	0.30	0.13[b]	0.34	0.07[b]	0.25	0.13	0.34
Meat Shop	0.31[c]	0.47	0.24[c]	0.43	0.35[a,b,d,e]	0.48	0.20[c]	0.40	0.26[c]	0.44	0.28	0.45
Farmers' Markets	0.12[c]	0.32	0.05	0.23	0.02[a]	0.15	0.05	0.23	0.08	0.27	0.06	0.23
Direct from Producer	0.02[e]	0.14	0.02[e]	0.13	0.03[e]	0.18	0.02[e]	0.15	0.08[a,b,c,d]	0.27	0.04	0.19
Internet	0.06	0.24	0.04	0.19	0.05	0.22	0.04	0.20	0.04	0.21	0.05	0.21
Have Purchased Natural Beef (Yes = 1)	0.33[b,e]	0.47	0.64[a,c,d,e]	0.49	0.33[b,e]	0.47	0.38[b,e]	0.49	0.16[a,b,c,d]	0.37	0.35	0.48
Share of Price Premium Designated to Concern about ... (%)												
Personal Benefits	46.67	26.06	41.13[c,e]	24.63	49.22[b,d]	23.99	43.44[c,e]	24.16	54.17[b,d]	34.64	47.72	27.29
Broad Societal Benefits	21.54	16.23	21.35	19.45	23.01	18.56	23.64	20.89	22.17	27.51	22.56	21.15
Public Health Benefits	25.06[b,e]	17.99	33.53[a,c,d,e]	21.83	23.50[b,d,e]	19.76	27.99[b,c,e]	19.85	14.13[a,b,c,d]	15.98	23.96	19.96
Demographics (See Table 1)												
Gender	0.60[b,c,d]	0.50	0.82[a,e]	0.39	0.75[a,e]	0.44	0.85[a,c,e]	0.36	0.57[b,c,d]	0.50	0.72	0.45
Size of Hometown	3.23[d]	1.46	3.36[d]	1.51	3.44[d]	1.43	2.78[a,b,c,e]	1.37	3.15[d]	1.39	3.19	1.44
Income	3.29[e]	1.47	3.24	1.44	3.07	1.44	3.06	1.54	2.85[a]	1.49	3.07	1.48
Non-Caucasian	0.10	0.30	0.13	0.34	0.13	0.34	0.14	0.35	0.12	0.33	0.13	0.33
Single, No Dependents	0.23	0.43	0.24	0.43	0.19	0.39	0.21	0.41	0.26	0.44	0.22	0.42
Couple, No Dependents	0.44	0.50	0.51[d]	0.51	0.42	0.50	0.34[b]	0.48	0.40	0.49	0.41	0.49
Parent	0.21	0.41	0.24	0.43	0.20	0.40	0.20	0.40	0.16	0.37	0.20	0.40
Woman with Child	0.19	0.40	0.24	0.43	0.17	0.38	0.20	0.40	0.15	0.36	0.19	0.39

[a] Significantly different than Cluster 1, Quality Seekers, at the 5% level.
[b] Significantly different than Cluster 2, Health and Natural Consumers, at the 5% level.
[c] Significantly different than Cluster 3, Moderate Consumers, at the 5% level.
[d] Significantly different than Cluster 4, Empathetic Value Seekers, at the 5% level.
[e] Significantly different than Cluster 5, Price Conscious Consumers, at the 5% level.

Table 3b. Average attribute ratings for Colorado consumer clusters.

	Cluster 1: Quality Seekers ($n=52$)		Cluster 2: Health and Natural Consumers ($n=55$)		Cluster 3: Moderate Consumers ($n=123$)		Cluster 4: Empathetic Value Seekers ($n=94$)		Cluster 5: Price Conscious Consumers ($n=92$)		Full Sample ($n=416$)	
Variable	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
Open Range	2.44[b,d,e]	0.98	4.16[a,c,e]	0.76	2.59[b,d,e]	0.93	4.34[a,c,e]	0.77	1.58[a,b,c,d]	0.80	2.95	1.36
No Antibiotics	2.56[b,c,d,e]	0.96	4.23[a,c,d,e]	0.84	2.92[a,b,d,e]	0.99	4.57[a,b,c,e]	0.65	1.76[b,c,d,e]	0.89	3.17	1.37
No Hormones	2.65[b,c,d,e]	1.05	4.38[a,c,d,e]	0.78	3.18[a,b,d,e]	1.04	4.66[a,b,c,e]	0.60	1.77[a,b,c,d]	0.85	3.30	1.39
Natural	2.69[b,c,d,e]	0.94	4.05[a,c,d,e]	0.80	2.99[a,b,d,e]	0.91	4.36[a,b,c,e]	0.80	1.76[a,b,c,d]	0.79	3.13	1.27
Organic	2.21[b,c,d,e]	0.84	3.67[a,c,e]	1.00	1.97[a,b,c,e]	0.81	3.74[a,c,e]	1.20	1.27[a,b,c,d]	0.52	2.47	1.32
Grass-fed	2.25[b,c,d,e]	0.86	3.82[a,c,d,e]	0.77	2.67[a,b,d,e]	0.87	4.15[a,b,c,e]	0.94	1.71[a,b,c,d]	0.82	2.89	1.26
Preserve Streams	2.33[b,d,e]	0.94	3.60[a,c,d,e]	1.03	2.41[b,d,e]	0.93	3.91[a,b,c,e]	1.03	1.57[a,b,c,d]	0.83	2.71	1.29
Protect Endangered Species	2.42[b,d,e]	1.11	3.71[a,c,e]	0.99	2.39[b,d,e]	1.01	3.95[a,c,e]	1.06	1.58[a,b,c,d]	0.80	2.74	1.33
Humane Treatment	2.77[b,d,e]	1.04	4.07[a,c,d,e]	1.07	3.05[b,d,e]	1.05	4.48[a,b,c,e]	0.76	2.02[a,b,c,d]	0.98	3.25	1.32
Traceable from Farm to Consumer	2.77[b,c,d,e]	1.10	3.78[a,c,d,e]	0.85	3.28[a,b,d,e]	1.11	4.30[a,b,c,e]	0.95	1.89[a,b,c,d]	0.94	3.21	1.31
Country of Origin Labeling	2.63[b,c,d,e]	1.10	3.78[a,d,e]	0.99	3.46[a,d,e]	1.10	4.30[a,b,c,e]	1.01	1.99[a,b,c,d]	0.99	3.26	1.33
BSE Tested	3.81[b,c,d,e]	0.99	4.44[a,c,e]	0.94	4.12[a,b,d,e]	1.00	4.55[a,c,e]	0.82	2.92[a,b,c,d]	1.26	3.96	1.18
USDA Certified Organic	2.46[b,d,e]	0.92	3.96[a,c,d,e]	0.88	2.52[b,d,e]	0.96	3.62[a,b,c,e]	1.25	1.52[a,b,c,d]	0.78	2.73	1.30
Value for Price	4.07[a,d,e]	0.76	4.36[a,d]	0.73	4.39[a,d]	0.70	4.54[a,b,c,e]	0.79	4.32[a,d]	0.75	4.37	0.75
Nutritional Value	3.25[b,c,d,e]	0.86	3.95[a,c,e]	0.95	3.82[a,b,c,d]	0.77	4.09[a,c,e]	0.92	2.87[a,b,c,d]	1.06	3.62	1.02
Percent Lean	3.58[b,c,d]	0.91	4.15[a,c,e]	1.01	4.02[a,d,e]	0.72	4.33[a,c,e]	0.69	3.42[b,c,d]	1.08	3.92	0.93
Fresh	3.48[b,d,e]	0.96	4.07[a,c,e]	0.92	3.59[b,d,e]	1.01	4.07[a,c,e]	0.94	3.05[a,b,c,d]	1.01	3.63	1.05
Aged >14 days	2.44[b,c,d,e]	1.02	3.13[a,c,e]	1.19	2.89[a,b,d,e]	1.05	3.12[a,c,e]	1.23	2.01[a,b,c,d]	0.97	2.72	1.17
Boneless	3.02[d]	0.98	3.35[e]	1.20	3.11[d,e]	1.08	3.54[a,c,e]	1.09	2.82[b,c,d]	1.02	3.16	1.10
Premium Brand	3.12[d,e]	0.92	3.44[e]	1.21	3.34[e]	0.99	3.51[a,e]	1.22	2.50[a,b,c,d]	1.08	3.18	1.15
Ready to Heat	2.54	1.13	2.55	1.12	2.47	1.07	2.67[e]	1.16	2.35[d]	1.11	2.51	1.11
Size of Package	3.54[b,c,d,e]	0.90	3.91[a,e]	0.97	3.78[a,e]	0.84	3.71[a,e]	1.15	3.20[a,b,c,d]	1.14	3.62	1.03
Pre-seasoned	2.13[d,e]	0.84	2.16[d,e]	0.98	1.96	0.97	1.83[a,b]	1.02	1.77[a,b]	0.94	1.94	0.97

[a] Significantly different than Cluster 1, Quality Seekers, at the 5% level.
[b] Significantly different than Cluster 2, Health and Natural Consumers, at the 5% level.
[c] Significantly different than Cluster 3, Moderate Consumers, at the 5% level.
[d] Significantly different than Cluster 4, Empathetic Value Seekers, at the 5% level.
[e] Significantly different than Cluster 5, Price Conscious Consumers, at the 5% level.

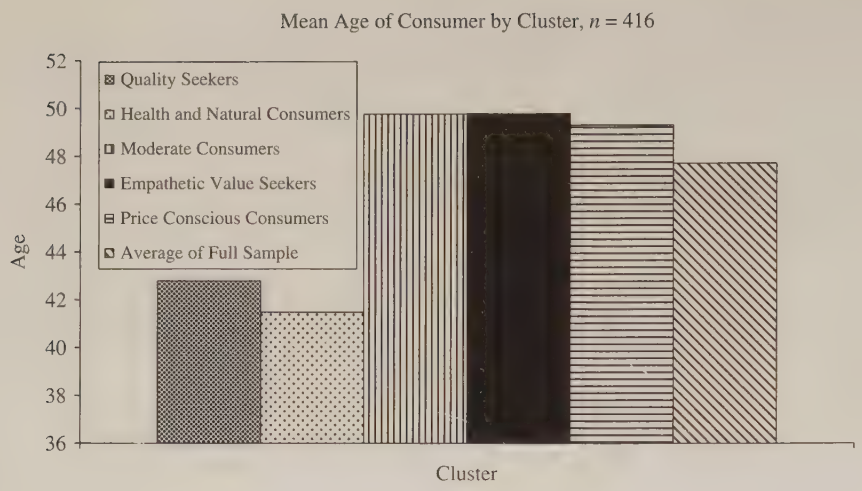

Figure 1. Consumer age profile by cluster.

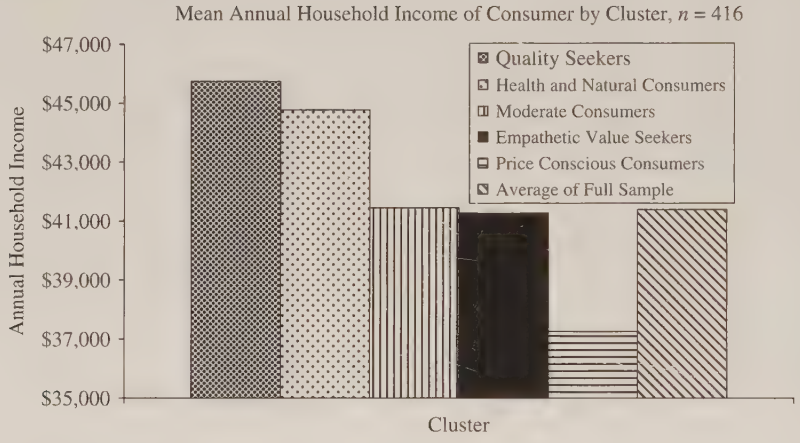

Figure 2. Consumer income profile by cluster.

Well-organized Eco-families, and represent the best potential consumer targets for CHR's current marketing strategies and product position. Thus, these clusters receive the most attention in defining the customer base, but other segments will be the comparative baseline from which to contrast the targeted consumers' attitudes and behavior. The third cluster, titled Moderate Consumers, includes 123 respondents (29.6%), the fourth is Empathetic Value Seekers (94 or 22.6%), and the last is the Price Conscious Consumers (92 or 22.1%).

First, we can explore basic demographic differences among the five clusters. Figure 1 indicates that targeted consumers (Quality Seekers and Health and Natural Consumers) are a bit younger than the sample average of 48 years. Table 3a indicates that the full sample is primarily female (over 70%), but that one of our targeted segments, Quality Seekers, are significantly more male than the others, as are the Price Conscious Consumers. In contrast, Health and Natural Consumers, another target cluster, as well as Empathetic Value Seekers are relatively more female than the Moderate Consumers. The proportions of each cluster that are non-Caucasian (13% on average) are also shown in Table 3a, but there are no significant differences between clusters and the total sample in terms of ethnic background. Figure 2 illustrates the final demographic to be analyzed, income. Income is important when discussing a differentiated product with a slightly higher price, as household income often influences the amount of disposable income, and subsequently, price sensitivity (Fig. 3). Not surprisingly, one targeted consumer segment, Quality Seekers, has relatively higher income, while the Price Conscious consumers may feel unable to buy quality products because of relatively lower household income. While graphically there appear to be some income differences across clusters, it should be noted that the average incomes for these clusters were only significantly different among Quality Seekers and Price Conscious Consumers, thereby suggesting the long-held belief that only affluent consumers will purchase natural meat products is misleading, once other consumer preferences are considered.

Demographics were once the primary source of market analysis, because they were common descriptors of people, and were even used to make promotional print and televised media buys. However, for a more personal promotion and marketing strategy like the one that CHR and other niche producers might use, demographics are limited in

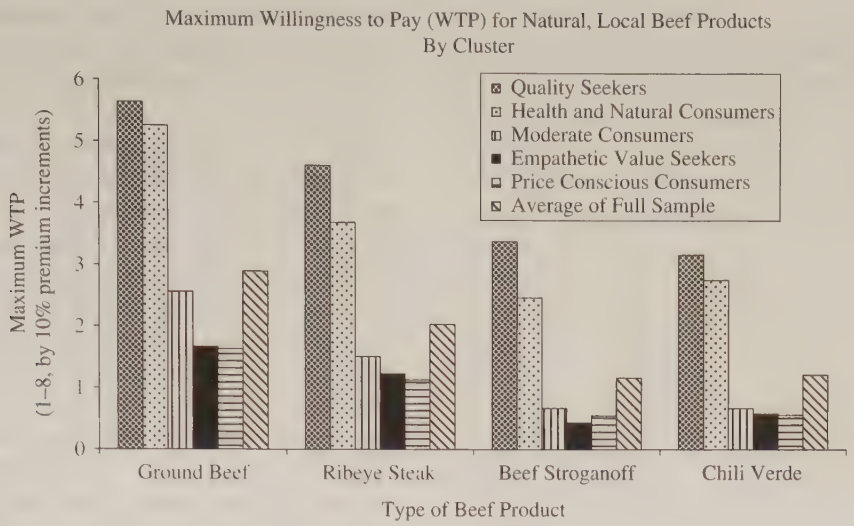

Figure 3. Consumer willingness to pay by consumer profile.

terms of the focus they give to market planning. Still, these demographic descriptions of our consumer clusters do allow us to understand what a representative consumer looks like, and begin to provide some basic information on how a marketing campaign might be structured.

Analysis of shopping and past consumption behavior is a more directed approach to analyzing the market potential for any one consumer cluster. Another important factor to understand about the potential natural beef consumers is their propensity to shop in less traditional food markets for some of their purchases, even if traditional supermarkets are still the dominant food shopping location. The shares of consumers in each cluster that use various alternative shops as their secondary meat shopping location are portrayed in Table 3a. Quality Seekers (cluster 1) are less likely to shop at meat shops than Moderate Consumers (cluster 3); however, they shop more at farmers' markets than Moderate Consumers. Health and Natural Consumers (cluster 2) are less likely than Moderate Consumers to shop at meat shops, and are more likely to shop at health food stores than all other clusters. Conversely, while Price Conscious Consumers (cluster 5) are less likely than some clusters to shop at either health food stores or meat shops, they are more likely than any other cluster to buy meat directly from producers (indicating some potential as a target market for lower priced, freezer beef marketers).

The most obvious signal of a consumer's propensity to purchase natural, local beef is their response to the question of whether they have purchased natural beef in the past. Table 3a provides evidence that the Health and Natural Consumers were more likely than all other clusters to have purchased natural beef products in the past, with 64% responding they had previously purchased natural beef. As a contrast, only 16% of Price Conscious consumers had made prior natural beef purchases, a share significantly lower than all other clusters. It is interesting to note that although cluster 1 (Quality Seekers) shows strong potential as a customer base, they still need to be convinced of the quality or other benefits that any natural beef products might offer (Table 3b).

The most stark differences among consumers were in their ratings of production and meat attributes, as the factor analysis indicated would be the case. One of the target clusters (Quality Seekers) rated natural, alternative and environmentally friendly production practices significantly lower than all other clusters except Moderate Consumers in a few cases (open range, preserve streams and endangered species, and humane treatment), and Price Conscious Consumers in all cases. Yet, Quality Seekers state they are willing to pay a significant premium for local, natural meat products. They also rated other attributes, such as freshness, package size and pre-seasoned, significantly lower than consumers in all or most of the other clusters, so that preferences about product attributes that directly influence their personal usage seem less important to this group. This outcome may simply indicate that Quality Seekers are primarily interested in the "local" attribute of the local, natural beef product and have a desire to support their local economy, with less particular emphasis on any tangible product attribute. This cluster presents a challenge to CHR, or similar natural beef producers, particularly if other regional beef producers choose to also market their qualifying beef products as "local." In order to sustain their competitive advantage with Quality Seekers, CHR may need to maintain a high-level of customer service, and will have to be innovative in order to continue to differentiate their product from commodity beef based on more intangible quality signals and "local" aspects this group seeks.

A sizeable cluster (Health and Natural Consumers and Empathetic Value Seekers) of consumers values the use of alternative production practices, so labeling of intrinsic production attributes should be a part of the larger marketing strategy. While Empathetic Value Seekers rate most production practice attributes high, they are not as willing to pay a premium for the local, natural beef product as Health and Natural Consumers. For the Empathetic

Value Seeker cluster, with its strong interest in beef raised with production assurances, there may be some opportunity to market large volume, low margin natural beef (freezer beef) at affordable prices, if producers are initially entering the market and are still working to develop a reputation and brand name. Price Conscious consumers, on the other hand, do not require production assurances but they have a propensity to buy direct.

As suggested throughout the discussion, and illustrated in Table 3a, all the consumer segments have significantly different levels of willingness to pay for the four types of beef products compared to one another (Fig. 3). The highest relative premium for each group is for ground beef, followed by ribeye steaks, and then the convenience entrée products. The two segments, Quality Seekers and Health and Natural Consumers, were targeted because of their willingness to pay the prices that CHR hopes to charge in order to meet their goals for returns to meat, but it should be noted that there is a significant difference in each segment's willingness to pay for ribeye steak and beef stroganoff. Consumers in these two segments represent a small enough market share so that a direct marketing producer group, such as CHR, could handle the volume necessary to supply a targeted region (in this case, Colorado's Western slope). The differences in each cluster's preference ratings for the beef attributes discussed previously can provide further direction for producer groups that are aspiring to develop alternative direct marketing strategies for each consumer segment or cluster. In addition to measuring possible premiums and to understanding preferences for different beef quality attributes, it is also helpful to understand *why* consumers are willing to pay these premiums.

As mentioned previously, there is increasing interest in understanding consumer attitudes toward the private and social benefits of the natural beef products that they purchase, and this survey attempted to elicit information with the following question:

> *There may be various reasons you prefer the natural beef products previously described above. Please estimate what share or percentage of your premium is based on the following: (Your answers must add up to 100 percent)*
> —— *Nutrition, quality, safety (Personal Benefits)*
> —— *Support local agriculture, environmental benefits (Broad Societal Benefits)*
> —— *Potential antibiotic resistance, unknown hormonal effects (Public Health Concerns)*
> —— *Other, Please Specify:* ————

On average, the sample reported that 48% of their premium was based on personal benefits. Public health concerns accounted for an average of 24%, broad societal benefits made up 23%, and other concerns represented 5% of the premium a consumer was willing to pay. Health and Natural consumers were more likely to designate a significantly higher (than the sample average) proportion of their premium for natural beef to public health benefits compared to all other clusters and a significantly lower proportion of their premium was assigned to personal benefits compared to Moderate and Price Conscious consumers. Conversely, Price Conscious consumers ascribed a significantly higher proportion of their premium for natural beef to personal benefits (compared to Health and Natural and Empathetic Value Seekers), and a significantly lower share of their premium was assigned to public health benefits relative to all other clusters. Interestingly, there were no significant differences in shares among the clusters for broader societal benefits. The sample of respondents who stated that a share of their premium was based on 'other' potential benefits specified these other benefits as including, but not limited to, the following: cost or price, product appearance, taste of the product, desire not to purchase natural beef, and preference for convenience. Another cluster analysis was performed that included all of these other variables, in addition to those listed in the first analysis. There were still five clusters, but the inclusion of these variables made the distribution across segments far less uniform, with two clusters dominating the sample, so they were excluded from subsequent cluster exercises.

Marketing Implications and Conclusions

The growth in natural meat sales in the United States has outpaced all other natural food sectors in recent years. The industry has responded with a number of beef products and brands to meet the needs of interested consumers. Such market innovations have also encouraged smaller producers, such as CHR, to explore strategies that allow them to capture the consumer market for meat raised using sustainable methods.

This research presents analysis of CHR's relevant market, Colorado consumers, using factor and cluster analysis. Given their discussions with customers while conducting direct sales, it was not surprising to them that the most important factor explaining almost two-thirds of the differences among consumer responses relates to production practices (use of antibiotics, hormones, and environmentally friendly grazing). Producer-members of CHR have used their sustainable practices as a product differentiation strategy, but as the cluster analysis indicates, customers are also motivated by a number of different factors.

Quality Seekers and Health and Natural Consumers (12.5 and 13.2% of the total sample, respectively) both indicate a willingness to pay a premium for natural, local beef. Quality Seekers' willingness to pay a premium for natural, local beef appears to be motivated by their perceptions of the premium quality of natural beef products. On the other hand, Health and Natural Consumers' willingness to pay premiums for natural, local beef products may be more altruistic in nature; this segment of consumers ranked production attributes such as 'no antibiotics', 'no hormones', and 'humane treatment'

significantly higher than the sample average. Additionally, Health and Natural consumers attributed a significantly lower (than the full sample) percentage of their premium to personal benefits, and a significantly higher percentage of their premium to public health benefits.

As a contrast to Quality Seekers and Health and Natural Consumers, Empathetic Value Seekers (22.6% of the sample) are not willing to pay a premium price for local, natural beef; however, CHR has still garnered some of their business by offering lower price points on some meat cuts (roasts, ground beef) that otherwise do not sell as quickly, in order to attract some price sensitive consumers. Overall, these results indicate the potential strength of production methods (and marketing of such quality differences) as product differentiation criteria.

This paper illustrates the type of market research that may be useful for beef producers seeking value-added marketing opportunities, as well as painting a bigger picture about the types of consumers who are fueling the growth in natural meat sales in the United States. On a broader scale, further analysis of these consumer segments could also help different meat market participants (supermarkets, meat shops, and producers who directly market their natural beef products) differentiate themselves by the type of consumer segment they hope to attract with their product offerings and their own market image. This information can inform emerging producer initiatives, helping them to differentiate their beef products through adoption of new production protocols, certification processes, and labeling of such attributes.

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Book Review

Good Growing—Why Organic Farming Works. By Leslie A. Duram. 2005. Bison Books, University of Nebroska Press, Lincoln, NE. 251 p. US$21.95, ISBN 0803266480, paperback.

Leslie A. Duram is an associate professor and chair of the Department of Geography and Environmental Resources at Southern Illinois University—Carbondale, but her roots are in Kansas, like mine, which of course helps her credentials when talking about agriculture. She explores organic farming from almost all possible angles—environmental, social, political, from the consumer's point of view, and most importantly, from the perspective of the farmers themselves. Five farms are described in some depth; both in the historical perspective of each farm, and also looking at the daily operations, and viewpoints of the operators. The farms are located in diverse regions of the country—California to Florida to upstate New York, with Colorado and Illinois thrown in to represent the central US. The chapter that describes these farms is probably the strongest in the entire book, and my main criticism of the volume is that more farms could/should have been explored, and more of the book could have been devoted to their stories.

The three chapters prior to the farm descriptions lay the groundwork for understanding their stories. The first is devoted to describing the geography of organic farming. This chapter provides a broad overview of the subject, is well referenced, and explores many topics that are interrelated when talking about organic agriculture. These include rural decline, government subsidies in agriculture, pesticides and health, as well as a definition of organic farming. Some of this ground has already been covered in other books about sustainable agriculture, but for new students of agriculture, it bears repeating.

The second chapter is about the science of organic farming, and the book is fairly thorough in reviewing relevant studies that compare conventional and organic systems in research trials, on farms, and in computer models. Her literature review includes some European literature as well as US, which is refreshing and informative, especially the description of organic farms from a landscape perspective. Some of this will be review for researchers who have been immersed in this topic for several years, but even the old-timers are likely to find something new here. In the third chapter, the social dimension is explored, including consumer surveys, marketing and direct marketing food systems, the role of large agri-business in the organic industry, and international trade.

The fourth chapter is where we hear from the farmers themselves. The farm descriptions are good, the photos could have been more engaging, but the stories were great. They captured the reality of farming, and the stress of putting it all together, and of keeping things going. The busyness of their lives leaves one wondering where the 'quality of life' part went—which is often in our definitions of sustainable agriculture. For example, the citrus grower who must work off farm for 4 months of the year to cover health insurance, and then work very long hours during the farming season.

The farmers' words reveal a lot and the parallel thoughts, trends, actions, and viewpoints of the farmers are well summarized in Chapter 5. The author also introduced her own bias in the selection of the farms, where she 'intentionally avoided both hippie granola and huge agri-business examples ... to feature the profitable medium-sized family organic farms that form much of organic production today and much of our hope for organic production in the future.' In my opinion, the diversity of farms on the landscape, especially organic farms, is one of the strengths of agriculture, and not including some of that diversity limits what this book is able to portray. However, the farms she chose do have regional and enterprise/product diversity, and in spite of the obvious differences in the farms, she is able to tease out some interesting trends/issues to summarize.

Her summary of the interviews in Chapter 5 includes economic factors, ecological concerns, social forces, and personal characteristics. Within each of these categories, several subtopics are explored, including cheap food expectations among consumers, low debt as a farm characteristic, and the role of tradition. In this chapter, as in some of the others, I might have chosen to organize the topics a bit differently, but the overall themes have a flow that works. Without conventional farms as a 'control' group, it might be a bit difficult for someone new to agriculture to realize how organic farmers view the world differently, and in some cases, there may be more common ground between the two groups than one would realize. A case in point is her discussion about the weather. Weather and climate play a crucial role in the management of just about ALL farms, not just organic farms (p. 160). One of my litmus tests for whether someone is really a farmer, whether large, medium, or small, is whether they watch/listen to/or otherwise check the weather forecast on at least a daily basis, if not several times a day.

The final chapter is a projection into the future of goals and suggestions. She reiterates some of her earlier arguments in favor of organic agriculture as a logical

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option of the future, due to its ecological and social benefits. She points out again the need for more funding for research in this area to level the playing field, and encourages researchers to explore new ground, and not just rehash the same studies over and over again. She warns of some of the risks of allowing 'Big O agribusiness' to dominate the markets, and concludes that 'medium to large family organic farms must also flourish.' I would agree with those statements, but also add that there is room for the not-so-big operations as well, and that much of the movement was founded by small, part-time operations. She suggests that in addition to an organic label, another certification, perhaps called 'Fair Share' be initiated, to signify that the producer was getting their fair share of the consumer dollar. This has taken off in marketing international products, such as coffee, but I haven't seen much of it in the US yet.

The appendix includes about 35 web-links and organizational contacts for more information, which is not an exhaustive list of everything available on organic agriculture, but would get one off to a good start. There are also about 250 reference citations, which will also help students of organic agriculture get up to speed.

In summary, this book would be excellent for students and for instructors looking for materials that would expose students to the main concepts and some of the history of organic agriculture. The farmer profiles will bring the concepts to life, and help the reader to understand the difficulty of that balancing act we call farming. To someone who has been in this field for a while, there won't be as much new material as one might like, but the international perspective comes through in several places, and the book is worth a good read. The farmer profiles were only 60 pages out of 250 total, and based on the title, I was hoping for more of that, and less review material similar to that found in other books about sustainable agriculture. A note to the publishers, I would have chosen a different cover photo; not unwashed carrots in a wheel-barrow. Carrots can really glow when washed—that's why most growers wash their carrots prior to taking them to market. The cover somehow leaves one with a sense that organic carrots aren't as clean as the ones you find in the store, which is a myth that the conventional agri-business would like consumers to believe. A photo capturing the beauty and diversity that can be part of an organic landscape, including the humans in the landscape, might be more appropriate. Overall, I enjoyed this book, and recommend it to others.

Rhonda R. Janke, Department of Horticulture, Forestry, and Recreation Resources, Kansas State University, Manhattan, KS 66506, USA.
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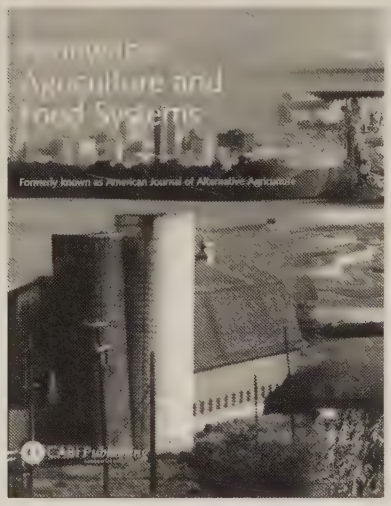

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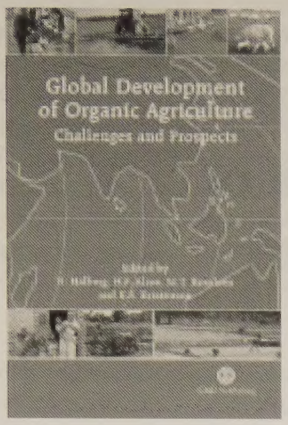

Global Development of Organic Agriculture: Challenges and Prospects

Edited by N Halberg, H F Alroe, M T Knudsen and E S Kristensen,
Danish Centre for Organic Farming, Denmark

May 2006 384 pages
HB 1 84593 078 9 £55.00 (US$100.00)

Readership

Researchers in organic agriculture, agricultural economics and rural development as well as NGO workers and policy makers.

Main Description

Agriculture and food systems, including organic agriculture, are undergoing a technological and structural modernisation strongly influenced by growing globalisation. Organic agricultural movements can be seen as a tangible effort towards more sustainable development. However, there are large differences between, on the one hand, industrialised farming and consumption based on global food chains and, on the other, smallholder farmers and resource poor people primarily linked in local food markets in low-income countries.

This book provides an overview of the potential role of organic agriculture in a global perspective. The book discusses in-depth political ecology, ecological justice, ecological economics and free trade with new insights on the challenges for organic agriculture. This is followed by the potential role of organic agriculture for improving soil fertility, nutrient cycling and food security and reducing veterinary medicine use, together with discussions of research needs and the importance of non-certified organic agriculture.

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Edited by D Blandford, The Pennsylvania State University, USA and
B Hill, University of London, Imperial College, UK

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Readership

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Main Description

This book explores the policy implications of growing pressures for economic adjustment in the agricultural sectors of developed countries. It starts by describing the recent history of adjustment in the food and agricultural sector and assesses the current and future pressures for adjustments and their implications. Chapters provide empirical evidence on the magnitude of future adjustment in the agricultural sector under a continuation of existing policies and analyze the factors that affect farmers' ability to adjust to economic change. The book concludes by identifying lessons to be learned from recent reforms and evaluating future policy options.

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1. Leopold, A. 1991. The farmer as a conservationist. In S.L. Flader and J.B. Callicott (eds). The River of the Mother of God and Other Essays by Aldo Leopold. University of Wisconsin Press, Madison, WI. p. 255–265.
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